

USE OF EVAPORATIVE COOLING SYSTEMS AND THEIR EFFECTS ON CORE BODY  
TEMPERATURE AND LYING TIMES IN DAIRY CATTLE

by

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## Abstract

Study 1 was performed to assess the effect of an evaporative cooling system (ECS) on core body temperature (CBT) and lying times in lactating dairy cows. Respiration rates and rear udder temperatures ( $T_u$ ) were also measured. Trial 1 contained 3 environmental treatments while trial 2 contained 2 environmental treatments. Treatments were: OFF (Cyclone fans and fog shut off), FAN (Cyclone fans only, no fog), and FANFOG (Cyclone fans and fog on) and cows exposed to these 3 environments were housed in a bedded pack barn (PACK) equipped with an ECS or a tie-stall barn (TIE). TIE and PACK cows moved between barns every 8 h for milking and both groups moved opposite of each other. Ambient, barn temperature and relative humidity (RH) measurements in addition to vaginal temperatures and lying times were recorded by sensors which took measurements at 1 min intervals.

Respiration rates (BPM), for PACK cows during FANFOG were reduced ( $P < 0.05$ ) when compared to TIE ( $53 \pm 2.0$  vs  $64 \pm 2.0$ , respectively) in trial 1. Similar results were found in trial 2. Rear udder temperature was measured and found to be decreased ( $P < 0.05$ ) in PACK cows while housed under FANFOG vs TIE in trial 1. These results could not be repeated in trial 2 because of greater ambient temperatures.

Core body temperature (CBT) was reduced during each trial as shown by less time spent above  $39.0^{\circ}\text{C}$  during FANFOG. During trial 2, PACK spent 5.7 and 8.5 h/d less over a CBT of  $39.0^{\circ}\text{C}$  compared to TIE cows. Total daily lying time was tracked and found to increase for cows exposed to the ECS during PACK but no difference between PACK and TIE.

In study 2, the same ECS was used but its effects on nonlactating dairy cows were studied. There was a treatment by h interaction for vaginal temperature showing the greatest effects during the afternoon h where FANFOG had numerically decreased CBT vs FAN. FANFOG cows spent reduced time over a CBT of  $39.0^{\circ}\text{C}$  and greater time  $< 38.0^{\circ}\text{C}$ . FANFOG cows also had increased lying times of 1.7 h/d compared to FAN.

**Key words:** heat stress, evaporative cooling, core body temperature, lying behavior

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## **Dedication**

I dedicate this work to my parents, Larry and Paulette Johnson. I am truly grateful for all the sacrifices you have made for me throughout the years. Seeing all your hard work throughout the years on the farm gave me the work ethic and made me the person I am today. I would not be where I am today without you.

# **Chapter 1 - Literature Review**

## Introduction

Heat stress in dairy cattle greatly affects the US and international dairy industry every year. It is estimated that total annual losses in the U.S. due to heat stress alone are ~ \$900 million (St. Pierre et al., 2003) even when current, economically feasible heat abatement systems are used. One thing to note, however, is that milk prices in 2003 were ~ \$13/cwt (National Agricultural Statistics Service). Using an average milk price from 2012-2014 of \$20.87/cwt (National Agricultural Statistics Service) and taking into account the greater feed prices seen today, this number rises in excess of \$1.3 billion in annual losses in the U.S. alone. This number is only likely to increase in the future as a result of increasing production levels in dairy cattle leading to greater body heat production, and also a shift trending towards locating dairy cattle in hotter climates. Advances in management by using cow cooling systems and nutritional strategies have helped to lessen some of the losses incurred due to heat stress but there are still significant economic losses every year. Although lactating dairy cattle tend to be most affected by heat stress, dry cows, heifers, and young calves also suffer from heat stress, leading to decreased production and growth rates. The greatest and most obvious impact heat stress has on dairy cattle would be the decrease in milk production. Economic losses due to decreased fertility, however, can also have a long lasting impact on the dairy herd. Reproduction programs have been implemented to alleviate some of these issues but every summer a major drop in fertility is seen. One of the reasons for this is that serum estradiol concentrations are lower from day 11 to 21 of the estrous cycle in cows that are exposed to heat stress conditions leading to decreased estrus expression (Wilson et al., 1998). In addition, embryo survival is compromised during heat stress, especially within the first few days after estrus (Ealy et al., 1993).

A common way of measuring heat load in a dairy cow is by using the temperature humidity index (THI) (Berry et al., 1964). THI is commonly used to estimate cooling requirements of dairy cattle to improve management strategies in order to alleviate heat stress. Traditionally, a THI value of 72 had been used as the cutoff point where production declined. More recently, however, Zimbelman et al. (2009) discovered that with today's higher producing dairy cows, a THI of 68 is the point at which productivity begins to decline. To understand why and how heat stress affects dairy cattle, it is important to understand the biology of the cow and

what is happening physiologically to cause the decrease in performance that we see annually throughout the summer months.

## **Etiology of Heat Stress**

In order to reduce economic losses due to heat stress, we must first understand what causes dairy cattle to become heat stressed. The biological mechanism by which heat stress leads to decreased production and reproduction is partly explained by reduced feed intake. It also includes, however, altered endocrine status, reduction in rumination and nutrient absorption, and increased maintenance requirements (Collier et al., 2005), which results in decreased nutrients and energy available for production. Due to the reduction in feed intake during heat stress, a majority of dairy cows enter into negative energy balance (NEBAL) (Baumgard et al., 2008). This is similar to the NEBAL observed in early lactation but not to the same extent. In addition to decreased feed intake, the thermoregulation process leads to an increase in blood flow to the skin to bring heat up from the body core to dissipate that heat via evaporation from the skin and respiratory tract. Thus, there is decreased blood flow to internal organs (i.e., digestive tract), therefore less movement of water and nutrients via the portal system that would have been used to support milk production (Finch 1986). Even though both early lactation and heat stressed cows are in NEBAL, there are major differences between the 2 groups (Baumgard et al., 2008).

In early lactation, dry matter intake (DMI) is insufficient to support peak milk production, causing cows to enter into NEBAL because they simply cannot consume enough energy to meet their requirements for milk production. For this reason, these cows begin to mobilize body fat in order to meet their energy requirements. Changes in both carbohydrate and lipid metabolism help ensure partitioning of dietary and tissue derived nutrients towards the mammary gland (Bauman and Currie et al., 1980). In the early lactation cow, circulating insulin levels are reduced; insulin is an anti-lipolytic signal. Due to the reduction of insulin during early lactation, these cows are able to mobilize body fat to meet their energy needs. As a result of body fat mobilization, it is very common for early lactating cows to have increased non-esterified fatty acid (NEFA) levels in the blood. This allows glucose to be used by the mammary gland for milk production. If, however, the early lactation cow becomes heat stressed, changes

in metabolism occur. In a recent study, 2 groups of early lactation cows were pair fed. One group was exposed to heat stress conditions while the pair fed group was housed under thermoneutral conditions. NEFA levels were similar for each group prepartum but the heat stressed group showed a significant reduction in NEFA levels postpartum, indicating impaired adipose tissue mobilization (Lamp et al., 2015). This would lead to increased glucose uptake by tissues (muscle) as an energy source, leaving less glucose available for the mammary gland, and thus decreasing milk output.

Similarly, heat stressed dairy cows also enter into NEBAL due to a reduction in DMI, but unlike early lactation cows, heat stressed induced NEBAL does not result in elevated plasma NEFA. Also, insulin levels do not decrease in heat stressed dairy cows like they do in early lactation cows. The greater levels of insulin sensitivity is likely a mechanism by which cattle decrease metabolic heat production, as oxidizing glucose is more efficient (Baldwin et al., 1980). This blocks the breakdown of fat, making the heat stressed dairy cow metabolically inflexible because of not being able to rely on adipose tissue to meet the energy needs of a cow that already is energy deficient due to a drop in DMI. The mammary gland requires glucose to synthesize the primary sugar in milk known as lactose. When an animal is heat stressed, it uses glucose as an energy source at a greater rate in an attempt to generate less metabolic heat. A major consequence of this is that less glucose is available for the mammary gland to produce lactose, leading to decreased milk production.

In a study done by Rhoads et al. (2009), the authors studied what percent decline in production could be attributed to decreased DMI and what percent was due to other factors. This was accomplished by pair feeding 2 groups of cows, 1 which was exposed to heat stress and the other which was kept under thermoneutral conditions. During the heat stress period under similar DMI between both groups, cows under heat stress had a milk yield of 21.5 kg/d while the pair-fed cows under thermoneutral conditions produced 29.0 kg/d. Thus, the authors reported that factors other than reduced DMI are responsible for 64% of the milk loss due to heat stress. These authors hypothesized that due to the fact that heat stressed dairy cows do not mobilize adipose tissue, glucose-sparing mechanisms that normally prevent severe reductions in milk yield during periods of inadequate intake are not present.

## Temperature Humidity Index

Heat stress is caused by a combination of environmental factors (air temperature, relative humidity (RH), solar radiation, air movement, and precipitation). Many different indices have been developed which combine these different environmental factors to measure the level of heat stress, but their use has generally been limited due to poor data availability (Bohmanova et al., 2007). Most studies on heat stress conducted today focus mainly on 2 of the environmental factors: air temperature and RH. Relative humidity is important because it has an impact on the rate of evaporative heat loss through the skin and lungs. The amount of moisture in the air becomes increasingly more important as the air temperature increases. Temperature humidity index is a single value representing the combined effects of temperature and RH. Temperature humidity index was originally developed by Thom (1958) and was later adapted for use in cattle by Berry et al. (1964). Traditionally, a THI of 72 was thought to be the point at which milk production declined and other effects of heat stress began to occur in dairy cows. This was discovered, however, using cows producing just 15.5 kg of milk/d. More recently, a study was conducted by Zimbelman et al. (2009), where they re-evaluated the THI threshold. It was hypothesized that the higher producing dairy cows today are more susceptible to heat stress and that the effects of heat stress start well before a THI of 72. Authors of this study found that physiological and production parameters indicated that a new THI threshold for lactating dairy cows producing greater than 35 kg/day should be 68 (Zimbelman et al., 2009). As milk production of dairy cattle continues to increase, cattle become more sensitive to heat stress conditions and they have a reduced threshold temperature at which milk loss begins to occur (Berman, 2005). This is due in part to the fact that as production levels rise, metabolic heat production is increased, causing the animal to become more heat stressed. In a study done by Purwanto et al. (1990), 10 cows were divided into 3 groups according to milk production (4 high, 4 intermediate, and 2 dry cows). Heat production for each group of cows was studied. Heat production from cows producing 18.5 and 31.6 kg/d of milk was 27.3 and 48.5% greater than the non-lactating cows. In addition, as milk production increased from 35 to 45 kg/d, the threshold temperature for heat stress was reduced by 5°C (Berman, 2005). Temperature humidity index is used today in the dairy industry to estimate the cooling requirements of dairy cattle in order to

improve management strategies to alleviate the effects of heat stress. It is beneficial to use THI as it incorporates both temperature and RH into one value.

## **Signs of Heat Stress**

When dairy cattle are suffering from heat stress, there are some typical signs that determine to what degree the cows are suffering. One of the easiest and most obvious is a decrease in milk production as well as DMI. A THI of 68-71 is known as the stress threshold. In this range of THI, we will begin to see an increase in cow respiration rate that exceeds 60 breaths per minute (BPM) (Smith et al. 2012). At this range, milk yield losses begin, and decreases in reproduction can also be detected. Rectal temperatures will often exceed 38.5°C, the normal body temperature of a dairy cow. At a THI of 72-79, mild-moderate heat stress begins where respiration rates will exceed 75 BPM and rectal temperatures exceed 39°C. Once THI reaches a level of 80-89, moderate-severe signs of heat stress will be seen, which include respiration rates exceeding 85 BPM and rectal temperatures exceeding 40°C. Finally, when THI reaches 90-99, severe heat stress occurs and cows will have a respiration rate in the range of 120-140 BPM and rectal temperatures exceeding 41°C (Smith et al., 2012).

Other typical signs that will often be seen in cattle suffering from heat stress will be open mouth breathing with panting and a protruding tongue. An increase in respiratory rate is a mechanism by which the cow can cool herself. The animal brings heat up from the body core and this airflow through the respiratory tract serves to cool the cow via evaporation from the surface. It was estimated by Finch (1986) that about 15% of heat from the body core is lost via the respiratory tract. This typically will not occur until the cow is suffering from severe heat stress as this is a “last-ditch” effort to reduce heat stress (Finch, 1986). High producing cows will show these symptoms before cows at inferior levels of production as the former are producing greater metabolic heat due to the increased levels of DMI to support the higher levels of milk production. Also, cows tend to group together during times of heat stress if not provided adequate heat abatement in an effort to locate themselves in the coolest part of the barn. One of these areas is around the water troughs. If cows are locating themselves around water troughs, this is an indicator that they are suffering from heat stress. In order to reduce the heat stress load



on dairy cattle, it is important to provide proper heat abatement strategies to allow the dairy cow to dissipate body heat more efficiently.

## **Consequences of Heat Stress**

Heat stress can affect the cow at different levels depending on where the cow is in lactation. Typically, heat stress will affect high producing, lactating dairy cows first as they produce the greatest amount of metabolic heat due to their greater DMI and high production levels. For this reason, producers commonly focus on this group first when cooling dairy cattle. Recent research, however, has shown that if cows are not cooled during the dry period, heat stress can cause major production losses in the following lactation and negatively affect the young, growing calf (Tao et al., 2011; Tao et al., 2012a).

### ***Heat Stress during Lactation***

Lactating dairy cows exposed to high ambient temperatures along with high RH or radiant energy from the sun respond with reduced milk yield. Heat stress during lactation can have major and long-lasting effects on DMI, milk production and composition, and reproduction. Milk yield was shown to decrease by 1.8 kg and DMI by 1.4 kg for each 0.55°C increase in core body temperature (CBT) (Johnson et al., 1963; Umphrey et al., 2001). In another study by Zimbelman et al. (2009), milk production decreased by 2.2 kg per day for each 24 hours above 68 THI or when minimum THI exceeded 65 or greater. In addition, increased metabolic disorders, health problems (i.e. rumen acidosis), slow heifer growth, and compromised milk quality (Collier et al., 1982; West, 2003) are often seen during heat stress. Studies have shown the impact of increased growth rates in heifers on future milk production. Research conducted by Moallem et al. (2010), showed an increase in first lactation milk production and 4% fat corrected milk of 10.3% and 7.1%, respectively for calves fed a greater plane of nutrition leading to greater calf growth. Thus, by reducing heat stress during heifer development, increased milk production could be expected once they reach lactation.

Seasonal patterns in milk yield and composition are evident in cattle. The month of parturition is known to have a large impact on milk yield and composition in the following

lactation. Milk protein yield is directly affected by temperature in that as ambient temperature increases, protein levels will typically decrease (Collier et al., 2012). One reason for this may be due to the production of heat shock proteins in response to heat stress by mammary epithelial cells, which would reduce milk protein synthesis (Collier et al., 2008). Cows that calved in December produced the highest levels of milk and milk protein, and those that calved in June produced the lowest, 92.8% of the maximum (Barash et al., 2001). In the same study done by Barash et al. (2001), the authors found that average milk production was reduced by 0.38 kg/°C and average protein production was reduced by 0.01 kg/°C. Along with a reduction in milk yield and milk protein, milk fat also typically decreases in the summer months. McDowell et al. (1976) found that milk fat, solids-not-fat, and milk protein percentage decreased 39.7, 18.9, and 16.9% when air temperature increased from 18 to 30°C.

It would be expected that feed efficiency would decrease in cows exposed to heat stress. The increase in maintenance associated with heat stress causes a shift in nutrients away from production processes due to mechanisms put in place by the animal in trying to maintain normal CBT, resulting in a decrease in feed efficiency. Therefore, anything that can be done to keep the cow cooler will result in greater feed efficiency and increased production levels.

The major challenge in high producing dairy cows under heat stress conditions is to dissipate heat produced by metabolic processes. Cows that are housed in hot climates produce additional heat relative to cool climates because of the greater physical activity (i.e. panting) necessary to enhance cooling in hot conditions. Improvements in genetics and management will continue to improve feed intake and milk yield in dairy cows leading to even greater metabolic heat production.

### ***Heat Stress during the Dry Period***

Dry cows are not the first group we often think of when cooling dairy cattle. Although lactating cows are the most important group to cool, dry cows can also suffer from heat stress if not adequately cooled. In a study done by Tao et al. (2012b) at the University of Florida, the effect of cooling heat stressed dairy cows during the dry period on insulin response was evaluated. The authors found that cooling heat stressed cows during the dry period tended to decrease circulating insulin levels and decreased plasma glucose concentration during the

postpartum period. Also, cooled cows had increased circulating NEFA in early lactation compared to non-cooled cows. This indicates that when cows are cooled during the dry period, they are able to mobilize adipose tissue postpartum to support milk production due to the decrease in circulating insulin. The decreased glucose levels in the cooled cows postpartum likely indicates that because of their greater milk production, more glucose was being used to produce the larger volume of milk lactose so less glucose was found in the blood compared to non-cooled cows.

In another study done by Tao et al. (2011), the authors looked at the effect of heat stress during the dry period on mammary gland development. It was discovered that heat stress tended to decrease mammary epithelial cell proliferation rate, which led to an increase in production in the subsequent lactation for cooled cows compared to heat stressed cows (33.9 vs. 28.9 kg/d respectively). In addition, heat stressed cows consumed less feed during the dry period when compared to cooled cows. By using heat abatement strategies during the dry period, we can greatly enhance milk production in the following lactation due to increased mammary epithelial cell proliferation rate, leading to increased mammary secretory cells.

Summer heat stress is also known to decrease immune function and increase metabolic disease of dairy cows. A study was conducted by do Amaral et al. (2011) where the authors studied the effects of heat stress abatement during the dry period on immune status throughout the transition period. It was found that during the transition period, cows housed with fans and sprinklers (cooled cows) had greater neutrophil function as measured by oxidative burst at 2 and 20 d post-calving compared to heat stressed cows. Since neutrophils are the first line of defense against disease, this indicates that cooled cows would be able to better fight off an infection and maintain their immune system, particularly during the transition period. In addition, when cows were injected with ovalbumin, cooled cows responded with superior production of IgG versus heat stressed cows during the dry period, indicating impaired humoral immunity due to heat stress during late gestation (do Amaral et al., 2011). When cows were induced with *Streptococcus uberis* at 5 d postpartum, cooled cows had greater numbers of white blood cells and neutrophils before and during the challenge (Thompson et al., 2014). This also shows that cows cooled during the dry period have an improved immune system in early lactation.

Decreased immune function in heat stressed dairy cows, particularly during the transition period, will increase the risk of metabolic disease postpartum. Thompson et al. (2012) found that cows exposed to heat stress during the dry period had greater incidence of postpartum disorders including mastitis, retained fetal membranes, and respiratory problems. With decreased white blood cell and neutrophil function in heat stressed dairy cows, an increase in postpartum disorders is not unexpected.

Cooling cows during the entire dry period cannot be overemphasized. When nonlactating dairy cows were cooled during the close-up period (final 3 weeks prior to parturition) only, milk production improved 1.4 kg/d versus non-cooled cows (Urdaz et al., 2006). When cows received cooling throughout the entire dry period, however, milk production increased ~5 kg/d over non-cooled cows (Tao et al., 2011, 2012b). Therefore, any time and money spent on cooling cows during the dry period will be well worth the time and effort, and will be money well spent.

### ***Effects of Heat Stress on the Calf***

Heat stress not only affects older animals but the young growing calf as well. Depending on the stage of gestation, nutrition can have a great effect on fetal growth and immune function of the neonate. Malnutrition, as seen during heat stress due to a decrease in DMI, as well as during late gestation, has been linked to inferior birth weights of calves, increased incidence of dystocia, and greater mortality and morbidity rates (Wu et al., 2006). Previous research has shown that calves born to cows experiencing heat stress have decreased birth weights and lower colostrum IgG content as well. In a study done by Nardone et al. (1997), 12 Holstein heifers were divided into two groups during the final three weeks of gestation up to 36 hours after parturition. One group was exposed to conditions that would cause heat stress and the other group was housed under thermoneutral conditions. Colostrum from cows exposed to heat stress had lower mean concentrations of IgG and IgA as well as other components in the colostrum. The authors concluded that the reason for decreased total protein from cows exposed to heat stress was because heat stress leads to reduced mammary blood flow, which leads to decreased nutrient supply going to the mammary gland.

Time of year in which the calf is born can have an impact on passive immunity between the calf and dam. Average serum protein concentrations were lowest (5.1 g/dl) for calves born during July and August and highest (5.7 g/dl) for those born during February (Donovan et al., 1986). Other studies, however, have found the opposite results. One thing to note is that the study done by Donovan et al. (1986) was carried out in a semitropical climate with high ambient summer temperatures whereas other studies were done in more temperate climates.

Several factors may contribute to impaired fetal growth in late gestation under heat stress. One such factor may be that heat stressed cows typically have a shorter gestation length that accounts for about 40% of the lesser birth weight in calves born to heat stressed dams (Monteiro et al., 2014). Another factor leading to impaired fetal growth is decreased blood flow to the uterus and placenta. This reduction in blood flow leads to decreased transport of oxygen and nutrients from the dam to the calf, resulting in impaired fetal growth (Monteiro et al., 2014). The last 2-months of gestation is critical to bovine fetal development and accounts for 60% of the body weight gain before birth (Bauman and Currie, 1980). According to Muller et al. (1975), the fetus of a Holstein dairy cow has an average daily gain of 0.5 kg in the final week of gestation. Heat stress during gestation is associated with decreased uterine blood flow and reduced placental size and function which limit oxygen diffusion into the fetal circulation (Dreiling et al., 1991). Another factor that may lead to decreased birth weight is the fact that DMI of the dam is reduced when exposed to heat stress, which leaves fewer nutrients for the fetus to grow.

In a study done by Tao et al. (2012a) at the University of Florida, the effect of heat stress during the dry period on the dam and the effect it had on the calf was evaluated. Thirty-four dry cows were housed in a freestall barn for 45 days before calving and were exposed to ambient environmental conditions or provided with cooling from fans and sprinklers. All calves were weighed at birth and subsequent measurements were evaluated on heifer calves only (n=21). Calves born to cows not provided with cooling weighed 36.5 kg compared to calves born to cows provided with cooling which weighed 42.5 kg. Compared with cooled heifers, heifers born to heat stressed cows had decreased weaning body weight (78.5 vs. 65.9 kg). Body weight from 3 to 7 months of age, however, were similar (154.6 vs. 146.4 kg) and wither height (104.8 vs. 103.4 cm) was also similar when cooled heifers were compared to the heat stressed group. Unlike the study done by Nardone et al. (1997), colostrum IgG content was not affected

by heat stress. Calves born to heat stressed dams, however, were less efficient in absorbing IgG from colostrum and had lesser serum IgG concentrations for the first 28 days of life than calves born to cooled cows. This indicates there was a reduction in passive transfer of immunity. These results confirm that calf body weight can be significantly impacted by heat stress during the final weeks of gestation.

In order to minimize the effects of heat stress on the growing fetus, it is important to cool cows during the dry period as heat stress leads to early parturition as well as decreased blood flow from the dam to fetus. Also, heat stress will lead to less DMI. All these factors combined will lead to decreased birth weights of the calf and decreased absorption of IgG, which are important for proper immune function.

### ***Heat Stress and Lameness***

Every year with the arrival of late summer or early fall, producers see a seasonal increase in lameness within their herds. Factors associated with the increase in lameness are heat stress, cow comfort and housing (increased standing times), and nutrition. Mean lying time decreased from 10.9 to 7.9 h/d from the coolest to the hottest part of the day and time spent standing in the alley increased from 2.6 to 4.5 h/d from the coolest to the hottest part of the day (Cook et al., 2007). Ideally, high producing dairy cows should be lying down for a minimum of 12 to 13 h/d (Cook et al., 2007). Oftentimes, non-infectious lesions are greatest following summer heat stress due to changes in daily time budgets and physiological adaptations, both of which result in greater risk for ruminal acidosis and the subsequent production of inferior claw horn (DeFrain et al., 2013). Claw horn lesions, such as sole ulcer, are believed to develop from increased pedal bone mobility due to changes in the corium at calving (Lischer et al., 2002). Factors that lead to an increase in standing time such as heat stress may intensify these changes by further compromising the structure of the claw. Time spent standing when the cow should be lying down may stress the bond between the third phalanx and the claw horn capsule, a bond that is already weakened around calving (Tarlton et al., 2002). Extra care should be taken during the summer months not to overcrowd pens as this will lead to an increase in stocking density, which will in turn lead to an increase in standing times. This will cause increased pressure on the foot,

leading to lameness. Also, with sprinklers often being used throughout the summer, the cow environment is often wetter, which can also be detrimental to hoof health.

### ***Heat Stress Effects on Reproduction and Fertility***

Heat stress is a major contributing factor to low fertility in dairy cattle. Heat stress has been shown to alter the following: duration of estrus, conception rate, uterine function, endocrine status, follicular growth and development, luteolytic mechanisms, early embryonic development, and fetal growth (Jordan, 2003). One of the principal mechanisms for which reduced conception rates are seen during summer heat stress is a result of the intensity of estrus being reduced, leading to fewer cows being found in estrus and being inseminated at the proper time. In summer months, dairy cows had just half the number of mounts per estrus compared to those in winter months (Thatcher and Collier, 1986). Wilson et al. (1998) found that serum estradiol concentrations were reduced in cows under heat stress from day 11 to 21 of the estrous cycle, explaining why fewer cows are found in estrus throughout the summer months. Also, the incidence of anestrus and silent ovulation are increased in summer (Her et al., 1988; Al-Katanani et al., 2002). When exposed to heat stress, the uterine environment of the cow becomes compromised due to decreased blood flow to the uterus and an increase in uterine temperature, leading to loss of the embryo (Roman-Ponce et al., 1978). The combination of these factors will lead to poor estrus detection and fewer animals getting inseminated to become pregnant.

Heat stress also delays follicle selection and lengthens the follicular wave, and thus has potential adverse effects on oocyte quality. Wolfenson et al. (1995) found that preovulatory follicles from heat stressed cows emerged 2 to 4 days earlier and may result in ovulation of older follicles, resulting in reduced fertility. Summer heat stress reduces the degree of dominance of the dominant follicle and more medium-sized subordinate follicles survive (Jordan, 2003). This can lead to a situation where more than one dominant follicle develops, which could explain the increase in twinning that is commonly seen during the summer months. Heat stress leads to an increase in the number of small (2 to 5 mm) follicles during day 11 to 15 of the estrous cycle, which in turn leads to a decrease in function of the dominant follicle (Trout et al., 1998). In a study done by Al-Katanani et al. (2002), effect of season and exposure to heat stress on oocyte development was studied. The authors found that the number of embryos that

developed to the blastocyst stage on day 8 after insemination was decreased during the warm season (April to September) versus cool season (October to March).

Temperature increases of just 0.5°C above normal body temperature (38.5°C) have been shown to lead to a decrease in pregnancy rates in dairy cattle (Gwazdauskas et al., 1973; Wolfenson et al., 1988). In an effort to study the effects of CBT on reproduction in lactating dairy cattle, cows were cooled 7 times per day for 30 minutes by sprinklers and forced ventilation. Another group of cows were housed under conditions without fans and sprinklers. The wetting cycles for the cooled group consisted of 30 seconds of wetting followed by 4.5 minutes of forced ventilation with 2 hours between cooling periods. CBT for cooled cows was maintained below 39°C throughout the duration of the study while CBT of non-cooled cows was greater than 39°C for most of the day. Conception rate at first insemination was greater (59%) in cooled cows versus non-cooled cows (17%). Pregnancy rates were also measured at days 90, 120, and 150 post-breeding. Cooled cows had greater pregnancy rates at all three time periods (44, 59, and 73 vs. 14, 31, and 31, respectively) (Wolfenson et al., 1988). Thus, according to these data, by using cooling methods to maintain CBT below 39°C, we can reduce the impact of heat stress on reproduction throughout the summer months. More recent data, however, shows that reproduction and fertility may be affected below 39°C rectal temperature. Recipient cows in an embryo transfer study showed decreased probability of pregnancy once average daily rectal temperatures exceeded 38°C and continued to decrease linearly as rectal temperature increased (Vasconcelos et al., 2011). Rectal temperatures in this study were taken between 0600 and 1000 h which is when we would expect cows to have the lowest rectal temperatures. This explains why reproductive efficiency began to decrease at 38°C, which is below the normal body temperature of a cow (38.5°C).

Heat stress can greatly affect the growing embryo, and the greatest susceptibility of the embryo to heat stress is immediately after the onset of estrus and during the early post-breeding period. Embryos become more resistant to the effects of heat stress as development progresses. Ealy et al. (1993) looked at how the developing embryo responded to heat stress at different stages of development (day 1, 3, 5, or 7). It was found that the embryo is most susceptible at day 1, but once the embryo reached day 3 of development it became more resistant to heat stress effects, but not completely resistant. Therefore, if we can keep the cow cooler throughout the breeding period by using heat abatement strategies to maintain lower rectal



temperatures, embryo survival should increase. Another strategy producers should consider using during summer heat stress is embryo transfer in place of timed artificial insemination. Embryo transfer may increase the number of pregnancies generated during the summer, but producers should consider the economic aspect of this strategy. Implanting embryos that developed under thermoneutral conditions into heat stressed cows 7 days post-estrus can bypass the critical time period (days 1-7) where embryos are most sensitive to heat stress (Putney et al., 1989).

Heat stress often induces negative energy balance in the dairy cow due to a reduction in DMI. As a result, less nutrients are supplied to the reproductive system for ovarian function and embryo growth. With decreased DMI during heat stress, decreased levels of insulin and glucose in the blood result. Insulin is required for the development of follicles and has beneficial effects on oocyte quality. In addition, glucose is the primary fuel for the ovary and embryo (De Renis et al., 2003). With decreased levels of insulin and glucose, fertility will be reduced. The lactating dairy cow is going to first direct nutrients to growth, maintenance, and lactation before supplying the reproductive organ.

Heat stress and its effects on reproduction can extend into the fall months as well as it takes approximately 40-50 days for antral follicles to develop into large dominant follicles and ovulate (Wilson et al., 1998). If heat stress occurs during the time of follicular development, both the follicle and oocyte become damaged, resulting in a less fertile oocyte, thus reducing fertility. This is why we often see reduced conception rates well into the cooler fall months of the year.

As milk production per cow continues to increase each year across the U.S., new and improved ways to manage heat stress are going to be necessary as milk production and fertility are inversely related. High producing dairy cattle have greater metabolic heat production due to increased DMI and milk production levels which leads to greater rectal temperatures thus, affecting embryonic survival and development.

## **Heat Stress Abatement Strategies**

Heat stress abatement strategies to alleviate some of the heat stress experienced in dairy cattle has become more common in recent years. There is still much room for improvement,

however, as dairy cattle continue to increase production levels, which leads to greater body heat production. The process that dairy cattle and other mammals use for thermoregulation is to maintain a core body temperature greater than the ambient temperature in order to allow heat to flow out from the core via 4 basic routes of heat exchange (conduction, convection, radiation, and evaporation). Conduction, convection, and radiation are known as sensible routes of heat loss and require a thermal gradient to operate. Heat loss by these 3 routes depends on the temperature difference between the cow and the surrounding environment. Evaporation, on the other hand, is known as insensible or latent heat loss and works on a vapor pressure gradient. When ambient temperatures approach body temperature as during heat stress, the only route of heat loss is via evaporation. If ambient conditions exceed body temperature, heat flow will reverse and the animal will become a heat sink (Collier et al., 2006).

Conduction is defined as the heat flow between 2 media or bodies in direct contact (Kadzere et al., 2002). The amount of conduction that takes place is dependent on the temperature difference between the 2 surfaces in contact as well as the conductance of the medium, and the amount of area in contact with each other. Type of bedding used can influence conductance. For example, sand bedding typically maintains a cooler surface temperature in comparison to wood shavings or manure solids. Therefore, it may be beneficial to use sand bedding as a heat abatement tool in the summer (Cummins, 1998). If the surface on which the cow is lying is hotter than the cow's body surface temperature, heat flow will reverse and the cow will gain heat by conduction adding to the metabolic heat load.

Convection is the movement of heat from the cow's body to the air. When cool air comes in contact with a warm body, a layer of air surrounding the body surface is heated and this heated air then rises, moving away from the body and carrying heat with it, hence cooling the cow (Kadzere et al., 2002). If the air temperature is greater than the body surface temperature of the cow, then heat flow will reverse resulting in increased body temperature in the cow. If there is a significant difference between the temperature of the air and the cow's body surface, convection will produce considerable cooling for the cow. Wind and fans blowing air over the cows would be an example of convective cooling. As air speed increases, the effects of convective cooling increase, making the animal feel cooler. Heat transfer during respiration is also a form of convective heat transfer (Kadzere et al., 2002).

Radiation is defined as the emission of heat towards and from the cow and surroundings, either directly from the sun (direct radiation) or from re-radiation from hot ground, fences, buildings, etc. Shading the cow is one way to decrease the heat load on the cow due to radiation. Black coated cows will radiate and absorb more heat than light colored cows at the same temperature.

Evaporation is the most efficient way for cows to dissipate body heat to the surrounding environment. Evaporation is considered the primary mechanism for heat loss and is most efficient in hot, dry climates. Cattle increase evaporative heat loss during heat stress by both panting and sweating (Kadzere et al., 2002). When dairy cattle sweat due to high ambient temperatures, the evaporation of this sweat will serve to cool the cow. Evaporation is dependent on air velocity around the cow. As air velocity increases, evaporation of sweat from the skin will also increase, making the cow feel cooler. Applying water to the cow's back at the feed bunk or in the holding pen and then letting this water evaporate, taking heat away from the cow's body surface, is another example of evaporative cooling. It is important to take into account the RH levels as this will affect the rate of evaporation through skin and lungs. At greater RH, less evaporation from the skin will occur due to greater amounts of water vapor in the surrounding environment. At a RH of 15%, the reduction in ambient temperature by evaporative cooling is in the range of 13-15°C. The reduction in ambient temperature declines steeply with rising RH. When ambient temperatures range from 32 to 42°C at 45% RH, the reduction in ambient temperature becomes just 30 to 40% of that at 15% RH. The reduction in the impact of evaporative cooling, however, can be overcome by increasing air velocity around the cow (Berman, 2006).

### ***Cooling the Cow***

One of the first steps that should be taken in cooling dairy cattle is to provide adequate shade to offer protection from direct and indirect solar radiation. It was estimated that total heat load could be reduced from 30 to 50% with a well-designed shade (Bond and Kelly, 1955). Shade is one of the easiest and most economical ways to reduce heat stress in dairy cattle. In a study done by Roman-Ponce et al. (1977) cows in a shaded versus unshaded environment had decreased rectal temperatures (38.9 and 39.4°C, respectively), reduced respiratory rate (54 and

82 breaths/minute, respectively), and yielded 10% more milk when shaded. Cattle with no shade had reduced ruminal contractions, greater rectal temperatures, and reduced milk yield compared with shaded cows.

There are numerous types of shading that can be used effectively, from trees to large barns to synthetic materials such as shade cloth. According to Armstrong (1994), a north-south orientation of shade is best to allow penetration of sunlight beneath the shade structure in order to dry the ground beneath as the shade moves from west to east throughout the day. Regardless of climate, a mature dairy cow requires 3.5 to 4.5 m<sup>2</sup> of space beneath the shade. Shades should be at least 4.3 m high to decrease the amount of reflected solar radiation from the shade roof to the cow (Collier et al., 2006).

Often times, additional cooling is necessary for lactating dairy cattle located in a hot climate. Even though shade helps to reduce solar radiation, there is no effect on air temperature or RH. The type of cooling system used on a dairy is highly dependent on climatic conditions. For a dairy located in an area that commonly sees high ambient temperatures along with high RH, evaporative cooling will be less effective compared to areas with a more arid climate. Air movement, however, is one type of cooling that can be used effectively under all types of climatic conditions. Air movement can come from wind in open lots and open free-stall barns or from mechanical ventilation with the installation of fans. As air temperature increases, however, air movement alone becomes less effective and must be used in combination with some other form of cooling such as evaporation by applying water either to the cow's back or to the air to decrease air temperature around the cow. Brouk et al. (2002) conducted a study at Kansas State University during the summer of 2001 in which different soaking frequencies were applied with or without fans to determine the effects of soaking frequencies on respiration rates, skin temperature, and vaginal body temperature. There were four different soaking treatments with and without supplemental airflow. Soaking frequencies were: control (no soaking), every 5 minutes, every 10 minutes, or every 15 minutes. Soaking cows every 5 minutes with supplemental air flow resulted in the fastest and largest drop in body temperature and respiration rate. Supplemental airflow without soaking resulted in little improvement compared with no soaking or airflow, indicating that airflow alone is not effective at cooling cows when ambient temperatures are increased (Brouk et al., 2002).

With the use of sprinkler systems to cool cows, water usage must be taken into account to assure that enough water and water pressure is available. Also, more water will be entering the lagoon so one must check that adequate lagoon capacity is available. Water usage can be reduced by applying water at the feed bunk only at certain times of the day, such as after milking when a majority of the cows will be at the feed bunk eating or when feed is pushed up. Another option to reduce water usage is decreased droplet size. A system that delivers a larger droplet size will use more water compared to a system that produces a mist or fog containing smaller water droplets. In a study done by Lin et al. (1998), fans and sprinklers were compared to fans and misters. The fan and sprinkler system used about 10-fold more water than the fan and mister system. Fan and misters were as effective as fan and sprinklers in maintaining DMI and milk yield in this study. If using a misting system, it is important to check that the hair coat is being completely soaked to the skin. If just the hair coat is wet, the mist will act as insulation to the cow leading to increased levels of heat stress.

### ***Cooling the Environment***

Another option in cow cooling is to cool the air around the cow in an attempt to reduce the negative effects of heat stress. Different methods can be used to accomplish this. Often times, cooling pads will be installed in a cross-ventilated or tunnel-ventilated barn which cools the air as it passes through the cooling pads. This cooler air is then pulled through the barn by exhaust fans on the opposite side of the barn. Also, high pressure mist or fogging systems in combination with fans have been used to cool the air around the cow. These methods can work very well in arid climates. High pressure systems create a water droplet size of 10 to 20 microns in diameter. Because of its small size, water droplets evaporate quickly as they move through the air, resulting in cooler air temperatures within the barn. Hinds (1999) studied the effects of 3 different water droplet sizes (20, 30, and 100 micron) and the amount of time required for evaporation. A water droplet of 20 microns required 254 seconds to fall 10 feet, while a 100 micron water droplet required just 10 seconds. Therefore, as water droplet size increases, evaporation time also increases. Hinds (1999) also studied the effects of differing RH levels on water droplet evaporation times. They found that a 20 micron water droplet evaporates in just 1 second at 50% RH, while it took 20 seconds to evaporate when RH increased to 70%. By

applying moisture to the air via an evaporative cooling system, RH levels are going to increase due to increased levels of water vapor present, making these systems more difficult to use in areas that typically see increased RH levels during the summer months. As RH increases, it becomes more difficult to cool the environment where the cows are housed (Fig. 1.1 and 1.2) (Smith et al., 2012).

If using one of these systems, it is important to realize that as air temperature is reduced due to water evaporation, the potential to evaporate moisture from the skin of cattle is also reduced due to greater RH levels. The net effect of evaporative cooling of air must be greater than the loss of cooling from moisture evaporation from the skin of cattle (Collier et al., 2006). Otherwise, heat stress will increase.

One way to overcome some of the increased RH levels is to increase air velocity around the cow, especially in the stalls, as this is where cows spend half their day and also where less body surface is exposed to dissipate body heat while lying. If there is enough air velocity, evaporative cooling systems may be used effectively in more humid climates. As air velocity is reduced, the convective and evaporative heat loss from the body surface is also reduced and increases the impact of the effects of RH on the cow. Berman (2006) recommended a minimum air velocity of 1.0 to 1.5 m/s at the cow level. He also suggested that an evaporative cooling system should not target uniform conditions in the housing space, and that air velocity should be directed over the resting area in order to encourage the cows to lie down more when heat stressed. Cook et al. (2007) looked at time budgets for 14 dairy cows housed under different climatic conditions with THI values ranging from 56.2 to 73.8. Mean lying time decreased from 10.9 to 7.9 h/d from the coolest to the hottest period. Benefits of increased lying time are greater blood flow through the udder when the animal is resting, leading to increased milk production. Grant (2007) proposed that each additional hour of resting time results in an increase of .91 to 1.59 kg of milk/day. Time spent standing in the alley also increased from 2.6 to 4.5 h/d from the coolest to the hottest period (Cook et al., 2007). Thus, if we can encourage cows to lie down more when heat stressed by increased cooling over the resting area, one could expect increased levels of production along with reduced lameness commonly seen during the summer months.

### ***Nutrition***

Although ventilation and cooling systems will have a greater impact on minimizing production and feed intake losses due to heat stress, nutrition is another way by which we can alleviate some of the heat stress put on dairy cattle during the hot summer months. Water is the most important nutrient for the dairy cow. Without it, DMI and milk production will decrease as milk is 87% water. Cows acclimated to 21.1°C and then exposed to 32.2°C ambient temperature for 2 weeks increased water consumption 110% and water losses from the respiratory tract and from the skin surface increased by 55% and 177%, respectively, at the greater temperature (McDowell and Weldy, 1960). These changes lead to increased water intake. Adequate water supply must be available at all times under hot conditions. Studies in climate chambers suggested that water needs under heat stress are 1.2 to 2 fold greater than that required of cows housed under thermoneutral conditions (Beede, 1993). Water tanks should be cleaned daily during the summer and a water quality test should be performed to check for any issues with minerals if water intakes are not where they should be. Also, water should be placed in close proximity to the cows and in the shade. Cows will often choose to continue lying down in shade versus standing up to get a drink of water if they need to walk through the sun to get there. Having water available as the cow exits the parlor is also very important. Beede (2006) found that cows drank as much as 50 to 60% of their total daily water intake immediately after milking. The author recommends providing 60.96 cm of linear trough space per cow when exiting the parlor. Inside the pen, a minimum of 2 water sources should be available and cows should never have to walk more than 15 meters to access water. A common recommendation is to provide 7.62 cm of linear trough space per cow in each pen.

Heat stress has long been known to adversely affect rumen health. When cows suffer from heat stress they begin to pant in order to dissipate heat. This increased respiration rate results in more carbon dioxide (CO<sub>2</sub>) being exhaled. In order to be an effective blood pH buffering system, the body needs to maintain a 20:1 bicarbonate (HCO<sub>3</sub><sup>-</sup>) to CO<sub>2</sub> ratio. Due to the hyperventilation induced decrease in blood CO<sub>2</sub>, the kidney secretes HCO<sub>3</sub><sup>-</sup> to maintain this ratio. This reduces the amount of HCO<sub>3</sub><sup>-</sup> that can be used (via saliva) to buffer and maintain a healthy rumen pH (Baumgard et al., 2008). In addition, panting cows drool more, which reduces the amount of saliva containing HCO<sub>3</sub><sup>-</sup> that normally would end up in the rumen. The reductions in saliva HCO<sub>3</sub><sup>-</sup> content and the decreased amount of saliva entering the rumen make the heat

stressed cow much more susceptible to subclinical and acute rumen acidosis (Baumgard et al., 2006).

One common practice in the dairy industry in an attempt to minimize metabolic heat production in dairy cows is to feed during the cooler parts of the day. This would mean feeding early in the morning before it gets hot and again later in the evening after temperatures have cooled down. A cow's peak heat production occurs about 3-4 hours after eating (Staples, 2007). Feeding early in the morning to allow for peak heat production to occur prior to the hot part of the day can alleviate some of the heat stress put on the cow. By feeding a second time in the evening, fresh feed is delivered, stimulating the cow to come to the feed bunk to eat after consuming very little feed during the hottest part of the day. In 2 Florida studies, lactating dairy cows having greater rectal temperatures averaging 41.0°C consumed 79% of their total daily DMI during the cooler part of the day (1600 to 0800) compared to cows with a rectal temperature of 39.3°C, which consumed 59% of feed during the cooler part of the day (Schneider et al., 1984; Mallonee et al., 1985).

It is common to alter diets fed to lactating dairy cows during the summer months in an effort to reduce the effects of heat stress. During the summer months, it is common to increase the energy density of the diet to account for the expected decline in DMI during the hottest parts of the year. This is usually done by feeding extra concentrates and reducing forage levels. In doing this, however, rumen pH will decline, leading to increased risk for rumen acidosis in a cow that already is at high risk due to less  $\text{HCO}_3^-$  entering the rumen. In addition, it is common for nutritionists to up the crude protein value of the ration in an attempt to account for the drop in DMI. If there is excess protein in the diet, however, energy must be used to convert the excess protein to urea which is then excreted in the feces. This process then leads to excess heat production in the animal (West, 1997). All these factors lead to an unhealthy rumen, which is why we see increased laminitis and milk fat depression in the hot summer months.

Another common way to increase energy density of the diet is to increase the amount of fat fed. Fat contains 2.5 times the energy level of concentrates and are utilized with a greater efficiency for milk production. Fats also have a decreased heat increment compared to starchy and fibrous feeds. Total heat loss decreased by 4.9 and 7.0% when cows were fed whole cottonseed at 15% of dietary DM or whole seed plus .54 kg/d of calcium salts of palm oil distillate respectively (Holter et al., 1992). Fat supplementation effects on milk production have



not been very consistent. With the use of fats in high fiber diets fed during heat stress, one may be able to maintain milk production and reduce the risk of rumen acidosis,

Mineral levels are another area of nutrition that needs to be checked during times of heat stress. When a cow is heat stressed, minerals are lost due to increased sweating. Potassium is the primary electrolyte lost in sweat of cattle. Along with the loss of potassium in sweat, the drop in DMI during heat stress results in less potassium intake through the diet. For this reason, it is common to increase potassium concentrations. It is recommended that diet potassium levels be increased to 1.5% of diet DM (Staples, 2007). In a study done by Schneider et al. (1984) potassium concentration of the diet increased from 1.0 to 1.5% using KCl, which resulted in a change of milk production from 39.7 to 40.8 kg/d.

Sodium is another mineral that should be fed at an increased rate during the summer. The heat stressed cow excretes more sodium in the urine. Just like potassium, with a decrease in DMI during heat stress, sodium intake is reduced. It is recommended that sodium concentrations be increased to 0.45 to 0.60% of dietary DM (Staples, 2007). When sodium concentration of the diet was increased from 0.67 to 0.96% using  $\text{NaHCO}_3$ , DMI was increased (39.9 to 42.8 kg/d) and milk production also increased (39.5 to 40.8 kg/d) (Schneider et al., 1984).

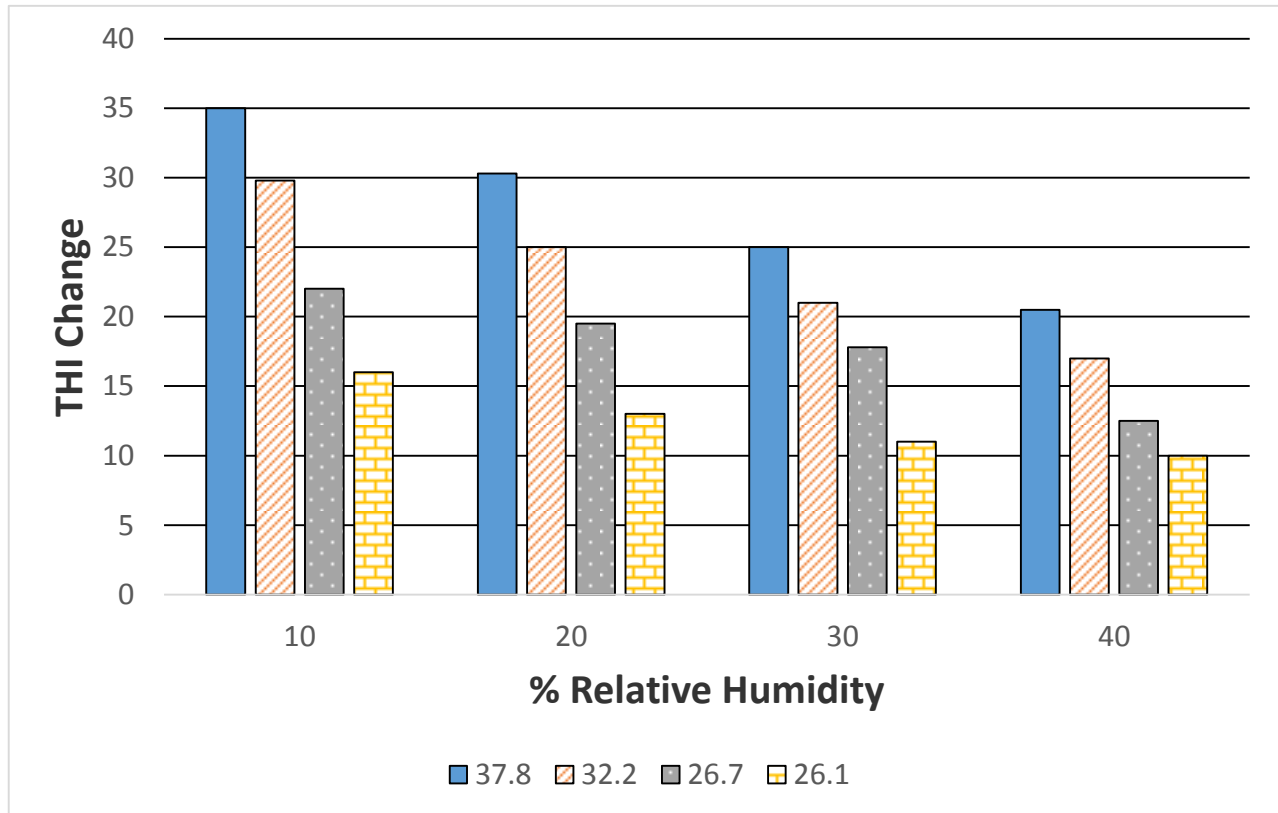
Trace mineral nutrition is another key area that should be considered to aid cows coping with heat stress. Any type of stress alters the efficiency of the immune system, making the cow more susceptible to infectious disease. Trace minerals that play a key role in immune function, oxidative metabolism, and energy metabolism in ruminants include zinc, copper, manganese, selenium, chromium, cobalt, and iron (Overton and Yasui, 2014). If any of these minerals are lacking in the diet, immune function may be compromised, leading to increased incidence of disease, particularly during the transition period. When these trace minerals are lacking, inadequate amounts of anti-oxidant enzymes are synthesized, leading to potential damage of tissue (Overton and Yasui, 2014). Common stressors such as heat stress lead to the accumulation of free radicals. If the anti-oxidants that prevent accumulation of free radicals are not present, damage may occur (Andrieu, 2008).

## **Conclusion**

Heat stress in the U.S. dairy industry leads to significant economic losses every year. Much research has been carried out looking at what is the cause for reduced production levels and it goes beyond just the typical drop in DMI often seen in the summer. The consequences of heat stress on the dairy cow can occur during lactation and the dry period. Also, calves born from cows exposed to heat stress conditions during the dry period show decreased levels of passive immunity and immune function as well as decreased birth weights. Due to many factors such as increased standing time and stress in the summer, an increase in lameness is seen that often carries into the fall months of the year. Also, reproduction and fertility take a major hit in the summer months. Throughout the years, different heat abatement strategies have been implemented. This can occur by cooling the cow directly or cooling the environment in which the cow is housed. Finally, nutritional programs can be implemented during the summer that will decrease or limit metabolic heat production in high producing dairy cows. Water, however, must not be overlooked as a decrease in water intake will surely lead to a decrease in production.

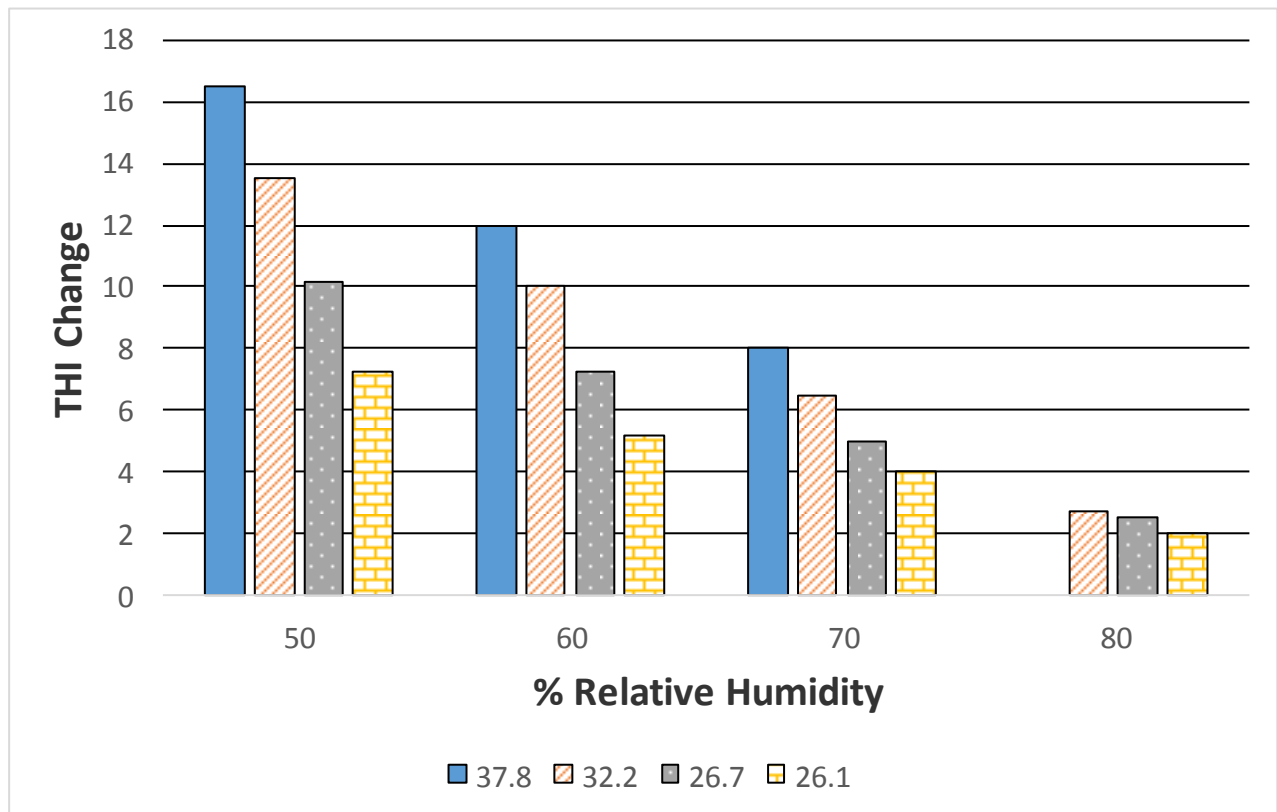
## Figures and Tables

**Figure 1.1** Potential THI change due to water evaporation at varying temperature (37.8, 32.2, 26.7, and 21.1°C) and relative humidity levels (10, 20, 30, and 40%).



Smith et al., 2012.

**Figure 1.2** Potential THI change due to water evaporation at varying temperature (37.8, 32.2, 26.7, and 21.1°C) and relative humidity levels (50, 60, 70, 80%).



Smith et al., 2012.

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## **Chapter 2 - Use of Evaporative Cooling Systems and its Effects on Core Body Temperature and Lying Times in Lactating Dairy Cows**

### **Abstract**

A study was performed to assess the effect of an evaporative cooling system (ECS) on respiration rates, rear udder temperature ( $T_u$ ), core body temperature (CBT), and lying times in lactating dairy cows. Two trials were conducted with the first having much cooler ambient conditions than trial 2. There were 3 environmental treatments in trial 1 and just 2 environmental treatments in trial 2 due to greater ambient temperatures. Treatments were: OFF (Cyclone fans and fog shut off), FAN (Cyclone fans only, no fog), and FANFOG (Cyclone fans and fog on) and cows exposed to these 3 environments were either housed in a bedded pack barn equipped with an ECS (Cyclone fans, Chippewa Falls, WI) or a tie-stall barn. Cows were divided into 2 treatment groups: TIE which spent 50% of the time in the tie-stall barn and 50% of the time in the bedded pack barn, and PACK which also spent 50% of the time in the tie-stall barn and 50% of the time in the bedded pack barn but opposite of TIE. OFF environment was not included in trial 2. Each cow was fitted with a vaginal temperature logger (HOBO U12, Onset Computer Corporation, Pocasset, MA), a neck collar that contained a sensor (HOBO Pro V2, Onset Computer Corporation, Pocasset, MA) to track temperature and relative humidity of the environment, and an electronic data logger (HOBO Pendant G Acceleration Data Logger, Onset Computer Corporation, Pocasset, MA) to track lying times. Ambient temperature and relative humidity (RH) were also recorded and all devices recorded at 1 min intervals.

Respiration rates, as measured by breaths/min (BPM), for PACK cows while in the FANFOG environment were reduced ( $P < 0.05$ ) when compared to TIE (53 vs 64, respectively) in trial 1. Similar results were found in trial 2. Rear udder temperature was measured and found to be decreased ( $P < 0.05$ ) in PACK cows while housed under FANFOG vs TIE in trial 1. These results could not be repeated in trial 2 because of greater ambient temperatures.

Categorical CBT data was broken up into the following categories:  $< 38.0^{\circ}\text{C}$ ,  $\geq 38.0^{\circ}\text{C}$ , and  $\geq 39.0^{\circ}\text{C}$ . During trial 1, cows without cooling (OFF) had elevated CBT  $\geq 39.0^{\circ}\text{C}$  for 4.6 more h/d ( $P = 0.01$ ) compared to cows housed under evaporative cooling (FANFOG). Cows

located in the bedded pack barn showed decreased CBT and spent 5.1 h/d less over a CBT of 39.0°C vs cows housed in the tie-stall barn ( $P = 0.01$ ). Similar results were found in trial 2 with cows housed under FANFOG spending decreased time above 39.0°C CBT. Cows housed in the bedded pack barn during FAN and FANFOG also spent fewer h/d over 39.0°C CBT vs tie-stall cows.

Total daily lying time results showed increased lying times during trial 1 when cows were housed under FAN and FANFOG treatments compared to OFF for PACK cows. Lying time decreased from 11.4 and 11.8 h/d during FAN and FANFOG to 8.6 h/d during OFF. Total lying time decreased for all treatments in trial 2 due to greater ambient temperatures. While no differences were found between treatments in trial 2, cows housed in the tie-stall barn showed numerically greater total daily lying times during FAN and FANFOG compared to cows housed in the bedded pack barn. These results confirm that ECS (Cyclone fans) are effective at decreasing respiration rates,  $T_u$ , CBT, and lying times in lactating dairy cows.

**Key words:** heat stress, evaporative cooling, core body temperature, lying behavior

## Introduction

Heat stress greatly affects dairy cattle behavior and physiology (Collier et al., 2006) every year throughout the U.S. Not only does heat stress reduce milk production but it greatly decreases efficiencies for growth and reproduction and leads to animal welfare issues such as lameness. It has been estimated that heat stress costs the U.S. dairy industry ~\$900 million annually (St-Pierre et al., 2003). More recently, Scharf et al. (2014) estimated heat stress to have an economic impact of \$89.01/cow per year. Even though much progress has been made limiting the effects of heat stress on dairy cattle, we continue to see many negative effects of heat stress annually as milk production and metabolic heat production continue to increase in today's high producing dairy cows.

Core body temperature (CBT) and total lying time are very important in the production and profitability of dairy cattle. Maintaining a normal CBT is critical for lactating dairy cows to sustain production and reproduction throughout the summer months. Milk production declined

when rectal temperature exceeded 39.0°C for more than 16 h (Igono and Johnson, 1990). In addition, reproductive efficiency and fertility have been shown to decrease when CBT exceeds 39.0°C (Gwazdauskas et al., 1973; Wolfenson et al., 1988; Wilson et al., 1998). Meanwhile, mean lying time decreased from 10.9 to 7.9 h/d from the coolest to the hottest part of the d and time spent standing in the alley increased from 2.6 to 4.5 h/d from the coolest to the hottest part of the d; thus there is an inverse relationship between ambient temperature and lying times in dairy cattle (Cook et al., 2007). Ideally, high producing dairy cows should by lying down for a minimum of 12 to 13 h/d (Cook et al., 2007). Grant (2007) proposed that each additional hour of lying time results in an increase of .91 to 1.59 kg of milk/day. In addition, when cows do not have adequate lying times, animal welfare issues and lameness may be a concern (Fregonesi and Leaver, 2001). Therefore, cooling systems that are able to reduce CBT and increase lying times in summer are necessary and could greatly enhance profitability of the dairy herd.

Evaporative cooling systems (ECS) equipped with a fogging mechanism have been used to decrease the air temperature around the cow and increase the heat exchange between cow and environment (Berman, 2006). The fog cools the air as it moves through the facility aided by the movement of air provided from strategically placed fans throughout the facility. Our objective for this study was to evaluate the effect of using high velocity fans equipped with a fogging system and its effect on respiration rates, rear udder surface temperature ( $T_u$ ), CBT, and lying times in lactating Holstein dairy cows.

## **Materials and Methods**

### ***Animals and Facilities***

This study was conducted on a commercial dairy in NE Kansas that contained a tunnel ventilated tie-stall barn (78.0 m x 12.8 m containing 100 stalls), which had a stocking density of 100% and a compost-bedded pack barn (22.9 m x 11.6 m pack area) fitted with 2 Cyclone fans (CYC723230460, 1.83 m Cyclone with deflectors, 230/460V, 3 HP) provided by VES Environmental Solutions (Chippewa Falls, WI), which had an average stocking density of 86%. The tie-stall barn contained cooling cells on the east end of the barn and 7, 1.37 m (1.5 HP motors, 25,750 CFM/fan) exhaust fans (Del-Air Systems, Ltd., Humboldt, SK, Canada) on the west end. Cooling cells were turned on and off each d depending on ambient temperature and

relative humidity (**RH**) levels. The compost-bedded pack barn contained 2 Cyclone fans (60,000 CFM/fan) located over the bedded pack area along with a fogging system to cool the cows which turned on and off as needed depending on ambient temperature and RH values. The fog system ran at ~1,000 PSI resulting in a water droplet size of 10-17 microns with a flow rate of ~0.036 gal/min/nozzle with 15 nozzles/fan. The study consisted of 2 trials. Trial 1 was conducted from August 5 to August 11, 2014 while trial 2 was carried out from August 19 to August 23, 2014. Throughout both trials, cows were milked 3 times/d (0600, 1400, and 2200 h) and a total mixed ration (**TMR**) was fed 3 times daily (0530, 1330, and 2130 h). The TMR was formulated to meet or exceed the predicted nutrient requirements (NRC, 2001) for energy, protein, vitamins and minerals. The Institutional Animal Care and Use Committee at Kansas State University approved all experimental procedures.

### ***Experimental Design and Treatments***

Twelve lactating Holstein dairy cows were randomly assigned to 1 of 2 treatments (Table 2.1). Group 1 was made up of 6 cows that averaged  $195 \pm 93$  DIM and 2.3 lactations. Group 2 consisted of 6 cows averaging  $195 \pm 137$  DIM and 2.2 lactations. Both groups were moved back and forth between the bedded pack and tie-stall barns for milking every 8 h. While 1 group of 6 cows was in the tie-stall barn for milking, the other group of 6 cows was located in the bedded pack barn. **PACK** consists of the time period when these 12 cows were located in the bedded pack barn while **TIE** consists of cows while located in the tie-stall barn. In trial 1, there were 3 different environments: d 1 and 4 consisted of cyclone fans along with the fog (**FANFOG**), d 2 and 3 consisted of the cyclone fans but no fog (**FAN**), and d 5 and 6 were the control and was made up of no cyclone fans and no fog (**OFF**). These 3 different environments were compared to the tie-stall environment. In trial 2, d 1 and 2 were conducted with the cyclone fans and fogging system in full operation (**FANFOG**) while d 3 and 4 consisted of fans only (**FAN**). Since this study was conducted on a commercial dairy, no **OFF** treatment was included in trial 2 due to excessive ambient temperatures that would have put cows without any heat abatement at risk for greater heat stress.

For each trial, within each d, there were 3, 8 h time periods. Because each treatment group (TIE or PACK) was moved between barns every 8 h, it took a total of 2 d to complete an environment (OFF, FAN, or FANFOG).

In both trials ambient temperature and RH were measured at 1 min intervals with 2 weather stations located throughout the farm. Weather stations were composed of a sensor (HOBO Pro V2, Onset Computer Corporation, Pocasset, MA) and a solar radiation and moisture shield (M-RSA; Onset Computer Corporation, Pocasset, MA). Inside of each barn, 2 weather stations (HOBO Pro V2, Onset Computer Corporation, Pocasset, MA) were placed throughout the barn to track barn temperature and relative humidity at 1 min intervals.

Each cow in the study was fitted with a neck collar that contained a sensor (HOBO Pro V2, Onset Computer Corporation, Pocasset, MA) to track temperature and RH of the environment as the cow moved throughout the facilities. Each cow also received an intravaginal stainless steel temperature logger (HOBO U12, Onset Computer Corporation, Pocasset, MA) attached to a blank controlled internal drug-releasing device (CIDR; Pfizer Animal Health, New York, NY) that recorded vaginal temperature at 1 min intervals. Before the start of the study, each vaginal probe was validated in a water bath with a certified thermometer to ensure similar temperature responses. In addition, each cow was fitted with an electronic data logger (HOBO Pendant G Acceleration Data Logger, Onset Computer Corporation, Pocasset, MA) that was attached to the medial side of the right, hind leg by using vet wrap. The acceleration data logger was placed in a position such that the x-axis was parallel to the ground, the y-axis was perpendicular to the ground pointing upward, and the z-axis was parallel to the ground pointing away from the sagittal plane. The loggers recorded the g-force on the x, y, and z-axes at 1 min intervals throughout the duration of each trial. All recording devices were pre-programmed to begin recording at 2230 h on d 1 of each trial. Each of the data loggers were removed from the cows at the end of each trial and downloaded using Onset HOBOWare software (Onset Computer Corporation, Pocasset, MA), which converted the g-force readings into degrees of tilt. These data were exported into Microsoft Excel (Microsoft Corporation, Redmond, WA), and the degree of vertical tilt (y-axis) was used to determine the lying position of the animal, such that readings  $< 60^\circ$  indicated the cow standing, whereas readings  $\geq 60^\circ$  indicated the cow lying down (Ito et al., 2009). Standing and lying bouts of  $< 2$  min were ignored because these readings were likely associated with leg movements at the time of recording (Endres and Barberg, 2007). All data

loggers were programmed and managed by a single computer, allowing for synchronization of time.

Each d throughout trial 1, individual cow measurements were taken at 0600 h, 1200 h, and 1800 h. Measurements included: respiration rate, whether the cow was lying or standing,  $T_u$ , location in the barn, and the environment in which the cow was located. In trial 2, individual cow measurements were taken at 0600, 1200, 1400, 1600, and 1800 h. The same measurements were taken as in trial 1 in addition to: body surface temperature at the thurl (both right and left side), whether the hair coat was wet or dry, and if the cow was drooling or had a protruding tongue. Respiration rate was measured by counting the number of flank movements for 30 s and then multiplying by 2. Body surface temperature was taken using an infrared thermometer gun (Raytek Raynger MX; Model: 4KM98).

### ***Statistical Analysis***

Data for ambient and barn conditions, collar data, respiration rate, udder temperature, CBT, and lying times were averaged by h prior to analysis and assessed using a mixed model analysis in a switchback design utilizing h of d as a repeated measure in the MIXED procedure of SAS (version 9.4, SAS Institute Inc., Cary, NC). Group of cows in a given time period was considered to be the experimental unit and was included as the random effect. Significance was declared with a  $P$ -value of  $\leq 0.05$ , and trends were declared with a  $P$ -value between  $> 0.05$  and  $\leq 0.10$ .

Mean hourly temperature humidity index (**THI**) data was calculated using the formula  $THI = (9/5 \times T_{db} + 32) - [0.55 - (0.55 \times RH/100)] \times [(9/5 \times T_{db} + 32) - 58]$ , where  $T_{db}$  is dry-bulb temperature ( $^{\circ}C$ ; Zimbelman et al., 2009). Vaginal temperatures were used to determine mean 24-h CBT and mean hourly CBT. In addition, CBT data were used to determine the duration of time cows maintained a CBT above or below various temperatures each d. Lying behavior data were summarized by analyzing the angles recorded by the leg data loggers and total lying time was calculated for each cow.



## Results

### *Trial 1*

Ambient conditions throughout trial 1 (Table 2.3) were cooler than expected. Average THI during the entire experimental period was 71 while average maximum THI throughout the entire 6 d trial was 76. Peak THI occurred on d 1 of the trial and peaked at 80. Differences between the 3 environments for THI were detected and can be found in Fig. 2.1.

#### ***Respiration Rates***

Mean daily respiration rate was affected ( $P < 0.0001$ ) by environment and period. An environment (OFF, FAN, or FANFOG) by time period interaction was also detected ( $P = 0.02$ ). Respiration rates, as measured by breaths/min (**BPM**), (Fig. 2.2 and 2.3) for PACK cows while in the FANFOG environment were reduced ( $P < 0.05$ ) when compared to TIE ( $53 \pm 2.0$  vs  $64 \pm 2.0$ , respectively). Cooling cows with FANFOG vs control (OFF) reduced respiration rates from  $66 \pm 2.0$  during OFF to  $53 \pm 2.0$  during FANFOG ( $P < 0.0001$ ). During FAN, PACK cows had reduced respiration rates ( $53 \pm 2.0$ ) when compared to TIE ( $60 \pm 2.0$ ) ( $P = 0.05$ ). No differences were found during the control (OFF) environment.

When comparing respiration rates for PACK cows by time period (0600, 1200, and 1800 h) (Fig. 2.3), BPM increased gradually for FANFOG until 1200 h but decreased thereafter. When the evaporative cooling system (**ECS**) was shut off (OFF), however, respiration rates showed a steady increase throughout the d. No differences were found between the 3 environments at 0600 h, which was used as the baseline BPM for the d. No significant differences were found until 1800 h where FANFOG was decreased in comparison to OFF.

#### ***Rear Udder Temperature***

Significant effects were found for environment and period ( $P < 0.05$ ). FAN and FANFOG environments had decreased  $T_u$  ( $P < 0.0001$ ) when compared to OFF ( $33.2 \pm 0.21^\circ\text{C}$  and  $32.7 \pm 0.18^\circ\text{C}$  vs.  $34.0 \pm 0.18^\circ\text{C}$ , respectively).  $T_u$  (Fig.2.4) were greater ( $P < 0.05$ ) for PACK when compared to TIE during the OFF environment. No differences were detected,

however, when comparing treatment groups (TIE and PACK) during FAN and FANFOG. Although PACK cows showed numerically decreased  $T_u$  during FANFOG, no statistical difference was found. There was also a significant environment by period interaction ( $P < 0.0001$ ) where  $T_u$  was  $1.9^{\circ}\text{C}$  less for FANFOG compared to OFF during the 1200 h time period and  $1.4^{\circ}\text{C}$  less compared to OFF during the 1800 h time period ( $P < 0.05$ ).

### ***Vaginal Temperature (CBT)***

There was a significant environmental effect ( $P < 0.01$ ) when comparing FAN and FANFOG to OFF for CBT. Cows in the FAN or FANFOG environment had an average CBT of  $38.7 \pm 0.02^{\circ}\text{C}$  and  $38.6 \pm 0.02^{\circ}\text{C}$ , respectively, vs  $38.9 \pm 0.02^{\circ}\text{C}$  for cows during OFF. When comparing the bedded pack barn to the tie-stall barn, there was a treatment effect ( $P = 0.003$ ) during FANFOG with cows housed in the bedded pack barn with the Cyclone fans having reduced CBT ( $38.6 \pm 0.02^{\circ}\text{C}$ ) vs cows housed in the tie-stall barn (CBT of  $38.9 \pm 0.02^{\circ}\text{C}$ ) during the same time period. The same treatment effect was found during FAN but no treatment effect was found during OFF between PACK and TIE. An environment x period interaction was also found ( $P < 0.01$ ).

Despite cooler ambient temperatures in trial 1, cows without cooling (OFF) showed elevated CBT  $\geq 39.0^{\circ}\text{C}$  for 4.6 more h/d (Table 2.4) ( $P = 0.01$ ) compared to cows housed under evaporative cooling (FANFOG). There was a trend for FANFOG cows to spend greater time at a CBT of  $< 38.6^{\circ}\text{C}$  compared to OFF. Cows housed under FANFOG spent 4.2 more h/d at CBT  $< 38.6^{\circ}\text{C}$  than cows in the OFF environment ( $P = 0.06$ ). When the bedded pack barn was compared to the tie-stall barn during FANFOG, PACK cows showed decreased CBT ( $P = 0.01$ ) and spent 4.9 h/d less over a CBT of  $39^{\circ}\text{C}$  vs cows housed in the tie-stall barn and 6.5 h/d more at a CBT of less than  $38.6^{\circ}\text{C}$ . Similar results were found during FAN, where PACK cows spent 4.3 h/d less at a CBT  $\geq 39.0^{\circ}\text{C}$  ( $P = 0.02$ ) and 3.5 more h/d below a CBT of  $38.6^{\circ}\text{C}$  ( $P = 0.11$ ). No differences were found when comparing CBT for the 2 barns during OFF.

### ***Lying Times***

While no differences were found in lying time between FAN and FANFOG, cows housed under FAN showed a trend ( $P = 0.10$ ) for having greater total daily lying time while FANFOG showed increased lying time in comparison to OFF ( $P = 0.05$ ). No differences were found when comparing the bedded pack barn to the tie-stall barn except when the ECS was shut off in the bedded pack barn (OFF) which led to decreased lying times in cows housed in the bedded pack barn ( $P < 0.05$ ). Lying time data for trial 1 can be found in Table 2.6.

### ***Trial 2***

A second trial was conducted when ambient conditions (Table 2.3) were much warmer in comparison to trial 1 to see if greater effects between treatments could be found. Average THI during the trial was 78, while average maximum THI was 84. Peak THI occurred on d 2 of the trial and peaked at 85 (Fig. 2.6). In contrast to trial 1, THI never dropped below 68. THI were similar between the 3 environments allowing us to compare between each environment. Collar THI data were recorded and no differences were detected ( $P > 0.05$ ) within environment. We did, however, detect differences ( $P = 0.02$ ) between periods.

### ***Respiration Rates***

Respiration rates for PACK cows while experiencing the FAN and FANFOG environments were not different although there was a tendency ( $P < 0.10$ ) for decreased respiration rates during FANFOG ( $74 \pm 2.4$  and  $69 \pm 2.4$ , respectively). No differences were found when comparing treatment groups while under the FAN environment. During FANFOG, however, PACK ( $69 \pm 2.4$  BPM) showed decreased ( $P < 0.05$ ) BPM in comparison to TIE ( $76 \pm 2.4$  BPM) (Fig. 2.7). When comparing environment by time period (Fig. 2.8), although there were no statistical differences between treatments, FANFOG had numerically lower BPM vs FAN throughout the afternoon h. While housed under the FAN environment with no fog, BPM were greater ( $P < 0.05$ ) for the time periods 1400, 1600, and 1800 h when compared to baseline, 0600 h, and peaked at 1800 h at  $83 \pm 3.8$  BPM. When cows were housed with the ECS

(FANFOG), there were no differences between any of the time periods when compared to baseline, 0600 h, and BPM actually peaked at 1400 h and decreased thereafter for the remainder of the d.

### ***Rear Udder and Thurl Temperature***

In contrast to trial 1, FANFOG was not as effective at reducing  $T_u$  during greater environmental temperatures. There were no differences ( $P = 0.99$ ) in  $T_u$  between FAN and FANFOG ( $35.0 \pm .18$  and  $35.1 \pm .18$  °C, respectively). Although no difference was found for PACK cows when compared to TIE, PACK had numerically greater  $T_u$  during FAN and FANFOG (data not shown). When comparing environment by time period,  $T_u$  was decreased for FANFOG compared to FAN during the 1800 h time period ( $P < 0.05$ ) but no other significant environment by period interactions were found. It is expected that due to the greater environmental temperatures experienced in trial 2, cows were under greater levels of heat stress.

When comparing thurl temperature, an environmental effect ( $P < 0.0001$ ) was found for both the right and left side. Thurl temperature on the right side of the animal had a mean of  $34.3 \pm .18$ °C and  $33.6 \pm .18$ °C for FAN and FANFOG, respectively. Left thurl temperature had a mean of  $34.1 \pm .18$ ° and  $33.6 \pm .18$ °C for FAN and FANFOG, respectively.

### ***Vaginal Temperature (CBT)***

No differences were found when comparing average CBT for each treatment. Cows in the FAN and FANFOG environments had an average CBT of  $39.0 \pm 0.12$ °C while cows located in the tie-stall barn had a CBT of  $39.5 \pm 0.12$ °C and  $39.3 \pm 0.12$ °C during FAN and FANFOG, respectively. These results, however, were not significant ( $P > 0.05$ ). When looking at categorical CBT data, however, significant differences were found for total time/d spent above 39.0°C CBT. While housed in the bedded pack barn under FANFOG, cows showed reduced time/d above 39.0°C CBT compared to FAN (9.2 vs 14.6 h/d, respectively) ( $P = 0.05$ ). Also, cows housed in the bedded pack barn (PACK) spent decreased time above 39.0°C ( $P < 0.05$ ) versus cows housed in the tie-stall barn (TIE). This data can be found in Table 2.5.

## ***Lying Times***

Total daily lying time data can be found in Table 2.7. No differences were found for total daily lying time when comparing both FAN and FANFOG or comparing the bedded pack barn to the tie-stall barn. Cows housed in the tie-stall barn showed numerically greater total daily lying time but there were no significant differences between treatments.

## **Discussion**

The THI levels reached in trial 1 would be expected to cause mild-moderate (72-79 THI) heat stress in lactating dairy cows while THI levels in trial 2 would be expected to cause moderate-severe (80-89 THI) heat stress (Armstrong, 1994; Smith et al., 2012).

While both trials were under heat stressed environments, FAN and FANFOG were able to reduce respiration rates vs the OFF environment. Decreasing respiratory rates is important to lessen the degree of respiratory alkalosis in the blood, thus decreasing the degree of acidosis in heat stressed animals (West, 2003). Typically, a dairy cow is considered heat stressed when respiration rates exceed 60 BPM. For PACK cows in trial 1, both FAN and FANFOG were able to reduce respiratory rates below the 60 BPM threshold indicating reduced heat stress in this trial compared to control (OFF), which is in agreement with Smith et al. (2006). Breaths per minute increased gradually for FANFOG in trial 1 until 1200 h but then decreased throughout the afternoon when ambient temperatures were greatest. When the ECS was shut off (OFF), however, respiration rates showed a steady increase throughout the d. Greater respiratory rates occurred in trial 2 as a result of greater ambient temperatures. Dissipating body heat via respiration is an energy cost to the animal leaving less energy available to go towards milk production. Increased respiratory rate and panting is a “last-ditch” effort to reduce heat stress (Finch, 1986). By reducing respiration rates, we will enable the lactating dairy cow to avoid a state of metabolic acidosis triggered by hyperventilation causing disruption of the 20:1  $\text{HCO}_3^-$ : $\text{CO}_2$  ratio in the blood (Baumgard et al., 2008).

During heat stress, peripheral vasodilation and central vasoconstriction of blood vessels occurs in order to move heat from the body core to the body surface to dissipate heat (Farooq et al., 2010). The reduction in  $T_u$  in trial 1 is in agreement with Berman (2006) and indicates that

heat flow from internal organs to the body surface was less than the amount of heat removed via water evaporation (Berman, 2008). The forced ventilation from the evaporative cooling and fogging system was effective at cooling the air around the cow, thus decreasing  $T_u$  due either to decreased blood flow to the skin or increased removal of heat from the body surface. If skin surface temperature remains below 35°C the cow is able to dissipate heat via all 4 routes of heat exchange (discussed later in this section) (Collier et al., 2006). If, however, body surface temperature exceeds 35°C, milk yield reductions begin and evaporation becomes the primary route of heat loss (Collier et al., 2006). In trial 1,  $T_u$  remained below 35°C throughout the entire study period for all treatments due to cooler ambient conditions. In contrast, trial 2 had greater ambient temperatures which resulted in increased  $T_u$ . FAN  $T_u$  had a mean of  $35.0 \pm .18^\circ\text{C}$  and peaked at  $36.2 \pm .22^\circ\text{C}$  vs FANFOG which had a mean of  $35.1 \pm .18^\circ\text{C}$  and peaked at  $36.5 \pm .22^\circ\text{C}$  indicating greater heat stress compared to trial 1. This indicates that blood flow carrying heat from the internal organs to the body surface was greater than the amount of heat that could be removed via evaporation. Thus, cows were less efficient at dissipating body heat in trial 2. In addition, we hypothesized that due to heat flow moving via conduction from the bedded pack to the udder while the cow was lying down, this resulted in greater  $T_u$  when located on the bedded pack compared with TIE. Although not measured in this study, based on the results of Collier et al. (2006), the  $T_u$  levels reached in trial 2 indicate a drop in production and loss of heat via evaporation being used as the primary method of body heat dissipation.

The negative effects of heat stress on dairy cattle depends on multiple environmental factors including ambient temperature and RH as well as wind velocity. Temperature humidity index is an equation that incorporates ambient temperature and relative humidity but not wind velocity. The upper limit of the thermal neutral zone for dairy cattle has been cited as 25°C (Hahn, 1997; NRC, 1981). Also, Zimbelman et al. (2009), re-evaluated the THI threshold and discovered that lactating dairy cows become heat stressed at 68 THI rather than 72 THI. As temperature rises, losses in DMI and milk production increase (Rhoads et al., 2009). Not only is production affected by increased ambient temperatures but reproduction is also greatly affected (Trout et al., 1998; Wilson et al. 1998; Jordan, 2003; Bilby et al., 2008). Others have cited increased incidence of disease and infections during the summer months (Kadzere et al., 2002). Lameness often increases in the summer and extends in to the fall months due to changes in animal behavior (Cook et al., 2007). Another concern involves ruminal acidosis which often

occurs due to respiratory alkalosis and excessive salivation, both of which result in less bicarbonate entering the rumen (West, 2003).

Cows are capable of dissipating body heat via 4 main routes (convection, conduction, radiation, and evaporation). When ambient temperatures are low, dairy cows are able to dissipate heat via convection, conduction, and radiation which are known as sensible routes of heat loss and work on a temperature gradient. As ambient temperature approaches CBT, however, evaporation (latent heat loss which works on a vapor pressure gradient) becomes the main route of heat loss in dairy cattle and when ambient temperature is greater than CBT, heat flow will reverse and the animal will begin to take on heat and CBT will increase (Collier et al., 2006).

Research shows that a CBT of 39.0°C is a very critical temperature for lactating dairy cows. Much research has been conducted studying the impact of elevated CBT on reproductive efficiency and it was found that conception rate and fertility decreased once CBT exceeded 39°C (Gwazdauskas et al., 1973; Wolfenson et al., 1988). More recent data, however, showed that reproduction and fertility may be affected below 39°C CBT. Recipient cows in an embryo transfer study showed decreased probability of pregnancy once rectal temperatures (taken between 0600 h and 1000 h) exceeded 38°C and continued to decrease linearly as rectal temperature increased (Vasconcelos et al., 2011). The Cyclone fan ECS used in this study was effective at decreasing CBT as evidenced by less time spent above 39.0°C CBT during FANFOG. Igono and Johnson (1990) cited that milk production declined when rectal temperatures exceeded 39.0°C for more than 16 h. During trial 2 while cows were under greater heat stress, the ECS was able to reduce time/d spent above 39.0°C CBT to less than 16 h/d compared to cows housed in the tie-stall barn which spent 20.3 and 17.7 h/d  $\geq$  39.0°C CBT during FAN and FANFOG, respectively. Although not measured in this study, we would expect cows housed under the ECS (Cyclone fans) to better maintain production levels compared to tie-stall cows. These results are similar to other studies using ECS to cool cows (Ortiz et al., 2010, 2011).

We did find an environment by period interaction when looking at CBT. This is due to the fact that the ECS was in operation only during certain hours of the day (late morning until late evening). Therefore, we would expect that while the ECS was on, cooled cows would maintain reduced CBT compared to non-cooled cows but less of a difference or no difference

throughout the nighttime hours when the ECS was shut off. Cows under cooling throughout the day, however, maintained decreased CBT throughout the night due to a lesser rise in CBT during the afternoon hours.

During trial 1, the Cyclone fans were able to increase total daily lying time. In contrast to trial 1, total daily lying times during trial 2 were quite low. This was due to the greater amount of heat stress experienced during trial 2. While housed in the bedded pack barn during trial 2, cows maintained a total lying time of just 7.9 and 8.4 h/d during FAN and FANFOG, respectively. During the same time period, however, cows housed in the tie-stall barn had total daily lying times of 10.5 and 10.3 h/d during FAN and FANFOG, respectively. Cows will often increase total daily standing time when heat stressed in an attempt to dissipate greater body heat due to greater body surface area being exposed allowing increased heat loss via convection and evaporation. Cook et al. (2007) found that mean lying time decreased from 10.9 to 7.9 h/d from the coolest to the hottest part of the day and time spent standing in the alley increased from 2.6 to 4.5 h/d from the coolest to the hottest part of the day. Ideally, high producing dairy cows should be lying down for a minimum of 12 to 13 h/d (Cook et al., 2004). The great amount of heat stress experienced in trial 2 led to very low total daily lying times while cows were housed in the bedded pack barn under FAN and FANFOG. This could lead to increased lameness due to greater standing time. Benefits of increased lying time are greater blood flow through the udder when the animal is resting, leading to increased milk production. Grant (2007) proposed that each additional hour of resting time results in an increase of .91 to 1.59 kg of milk/d. Thus, if we can encourage cows to lie down more when heat stressed by increasing cooling over the resting area, one could expect increased levels of production along with reduced lameness commonly seen during the summer months.

Over the years, many different types of cooling systems have been developed in an effort to enhance heat loss in dairy cattle. Evaporative cooling systems have been shown to effectively cool the environment where cows are housed (Ryan et al., 1992; Ortiz et al., 2010). This creates a greater temperature gradient between cow and environment by cooling the air allowing the cow to dissipate more body heat.

The Cyclone fans used in the present experiment were high velocity fans which incorporated a fogging system. The fog evaporates as it moves through the air cooling the environment around the fan and fog. Hinds (1999) studied the effects of 3 different water



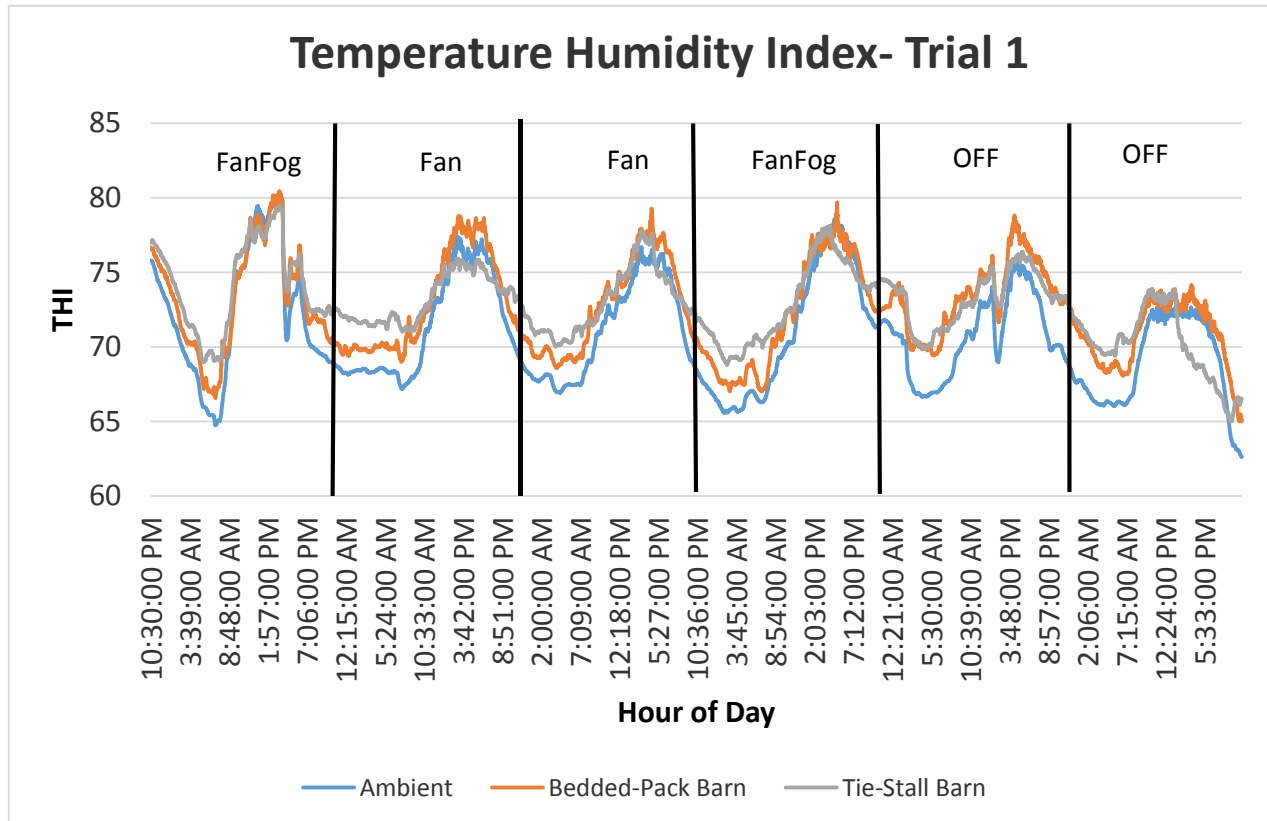
droplet sizes (20, 30, and 100 micron) and the amount of time required for evaporation. A water droplet of 20 microns required 254 seconds to fall 10 feet, while a 100 micron water droplet required just 10 seconds. Therefore, as water droplet size increases, evaporation time also increases. Hinds (1999) also studied the effects of differing RH levels on water droplet evaporation times. They found that a 20 micron water droplet evaporates in just 1 second at 50% RH, while it took 20 seconds to evaporate when RH increased to 70%. Therefore, water droplet size and RH levels are important considerations when choosing an effective cooling system. Due to evaporation of the fog, RH levels will increase, which decreases the vapor pressure gradient between the cow and environment leading to less efficient evaporative heat loss. Thus, the benefit of decreasing air temperature must be greater than the effect of increasing RH levels or greater heat stress will occur. If the air velocity used with fogging systems is not great enough, small water droplets will begin to accumulate on the cows' surface hair and act as an insulating barrier preventing dissipation of body heat (Hahn, 1985).

According to Janni et al. (2007), cows housed in a bedded pack barn should be allowed 7.4 m<sup>2</sup>/cow of pack area. The bedded pack barn in this study had an average stocking rate of 86% throughout the study which resulted in 8.85m<sup>2</sup>/cow of pack area. Meanwhile, the tie-stall barn maintained a stocking rate of 100% throughout the study. In addition, cows located in the bedded pack barn had greater air flow as measured by greater total CFM/cow. The 2 cyclone fans in the bedded pack barn were each rated at 80,000 CFM/fan resulting in a total of 160,000 CFM in the bedded pack barn. At any given time during the study, there was an average of 30 cows located in the bedded pack barn resulting in an average of 5,333 CFM/cow which was far greater than the average CFM/cow within the tie-stall barn. The 7 exhaust fans in the tie-stall barn were each rated at ~25,700 CFM/fan for a total of 180,000 CFM in the tie-stall barn. With more cows located in the tie-stall barn, however, this resulted in less total CFM/cow with an average of 1,800 CFM/cow. We recognize that the differences in stocking rate and total CFM/cow could affect the results found in this study.

## **Conclusions**

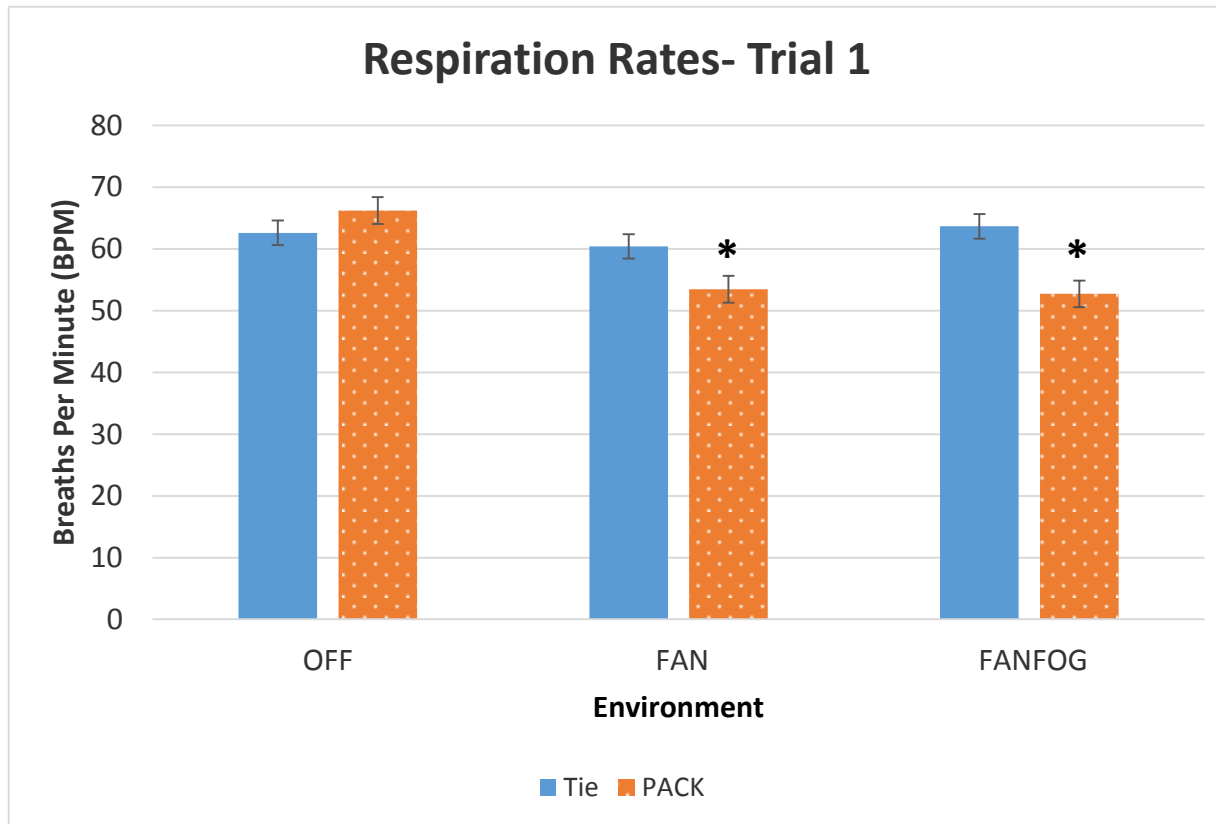
In this study, Cyclone fans and fog were effective at reducing respiration rates in lactating dairy cows while there were differing results between the 2 trials for  $T_{re}$ . Cows housed under the ECS (FANFOG and PACK cows) showed reduced CBT and spent fewer h/d above the critical CBT of 39.0°C. Cows also had greater lying times during trial 1 when the ECS was in full operation (FANFOG) while no differences were found between PACK and TIE. During trial 2, lying times decreased for all treatments due to greater ambient temperatures and no differences were found when comparing treatments. These results indicate that the ECS was effective in decreasing CBT which is the primary indicator of heat stress in lactating dairy cows which led to increased total daily lying times during trial 1.

## Figures and Tables



**Figure 2.1** Temperature Humidity Index (THI) for ambient, bedded pack and tie-stall barn conditions for the duration of trial 1. Type of treatment (OFF, FAN, or FANFOG) applied for each d is also listed.

Environment: OFF = Cows housed without the presence of Cyclone fans or fog; FAN = Cows housed with the presence of Cyclone fans but no fog; FANFOG = Cows housed with the evaporative cooling system in full operation which included Cyclone fans and fog.

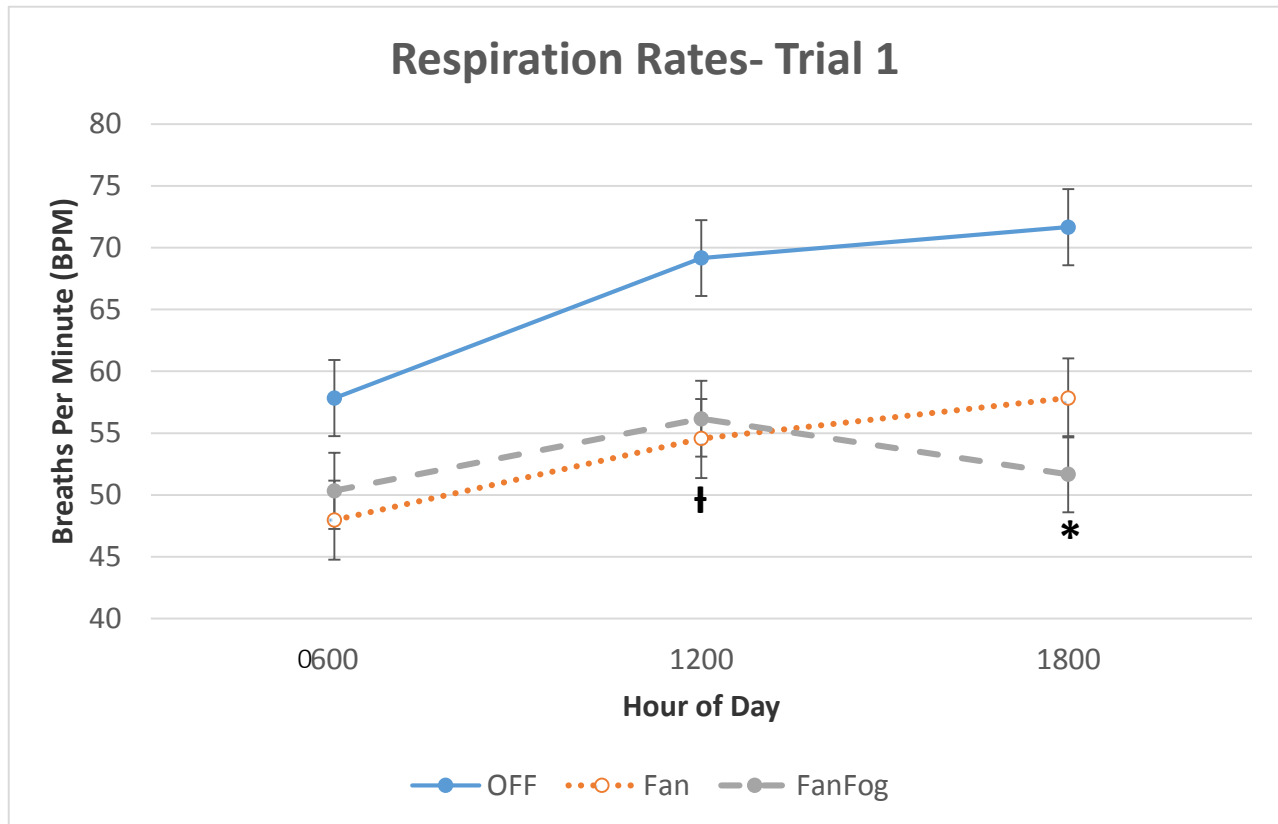


**Figure 2.2** Least squares means for respiration rates, measured in breaths/min (BPM), during OFF, FAN, and FANFOG for the 2 treatment groups during trial 1.

Environment: OFF = Cows housed without the presence of Cyclone fans or fog; FAN = Cows housed with the presence of Cyclone fans but no fog; FANFOG = Cows housed with the evaporative cooling system in full operation which included Cyclone fans and fog.

Treatment: TIE = Cows housed 50% of the time in the tie-stall barn and 50% of the time in the bedded-pack barn; PACK = Cows housed 50% of the time in the bedded pack barn and 50% of the time in the tie-stall barn moving opposite of TIE.

\* $P < 0.05$  vs TIE.

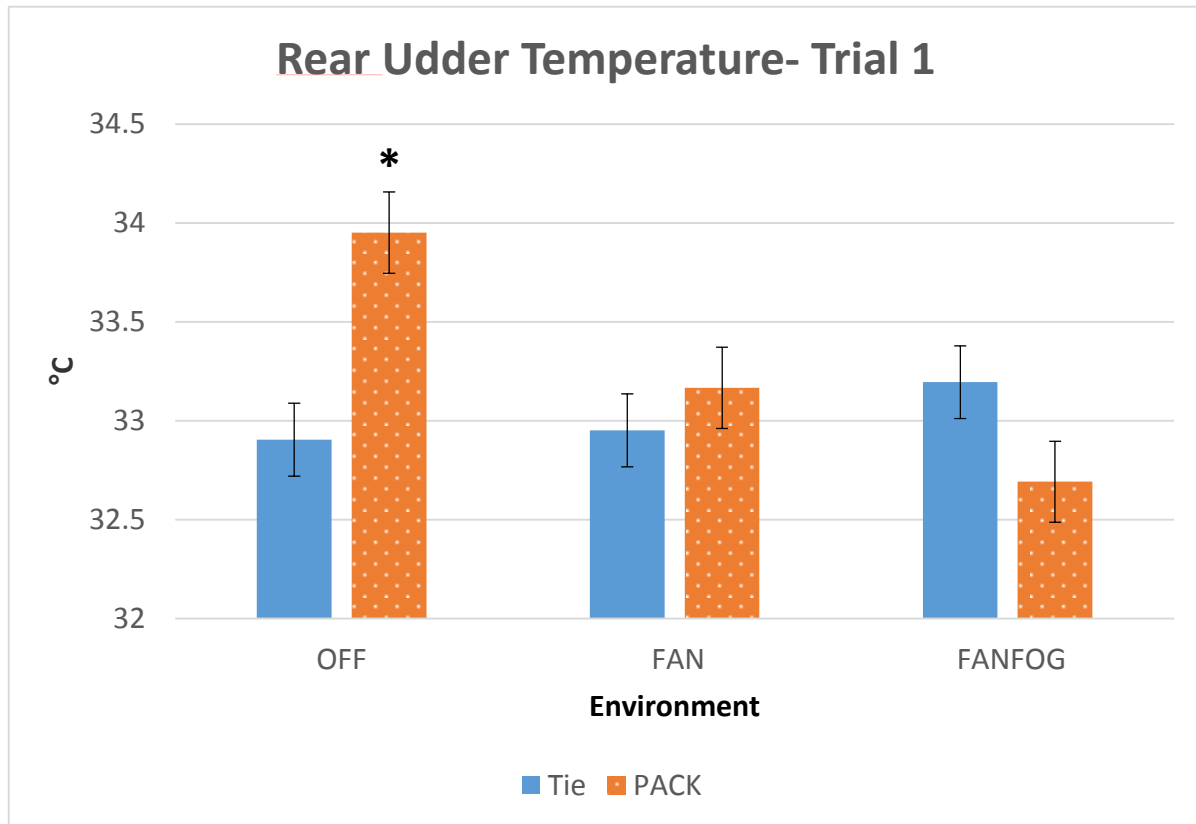


**Figure 2.3** Respiration rates, measured in breaths/min (BPM), by time period while located in the bedded pack barn during OFF, FAN, or FANFOG for trial 1.

Environment: OFF = Cows housed without the presence of Cyclone fans or fog; FAN = Cows housed with the presence of Cyclone fans but no fog; FANFOG = Cows housed with the evaporative cooling system in full operation which included Cyclone fans and fog.

\* $P < 0.05$  vs OFF.

<sup>†</sup> $P < 0.10$  vs OFF.

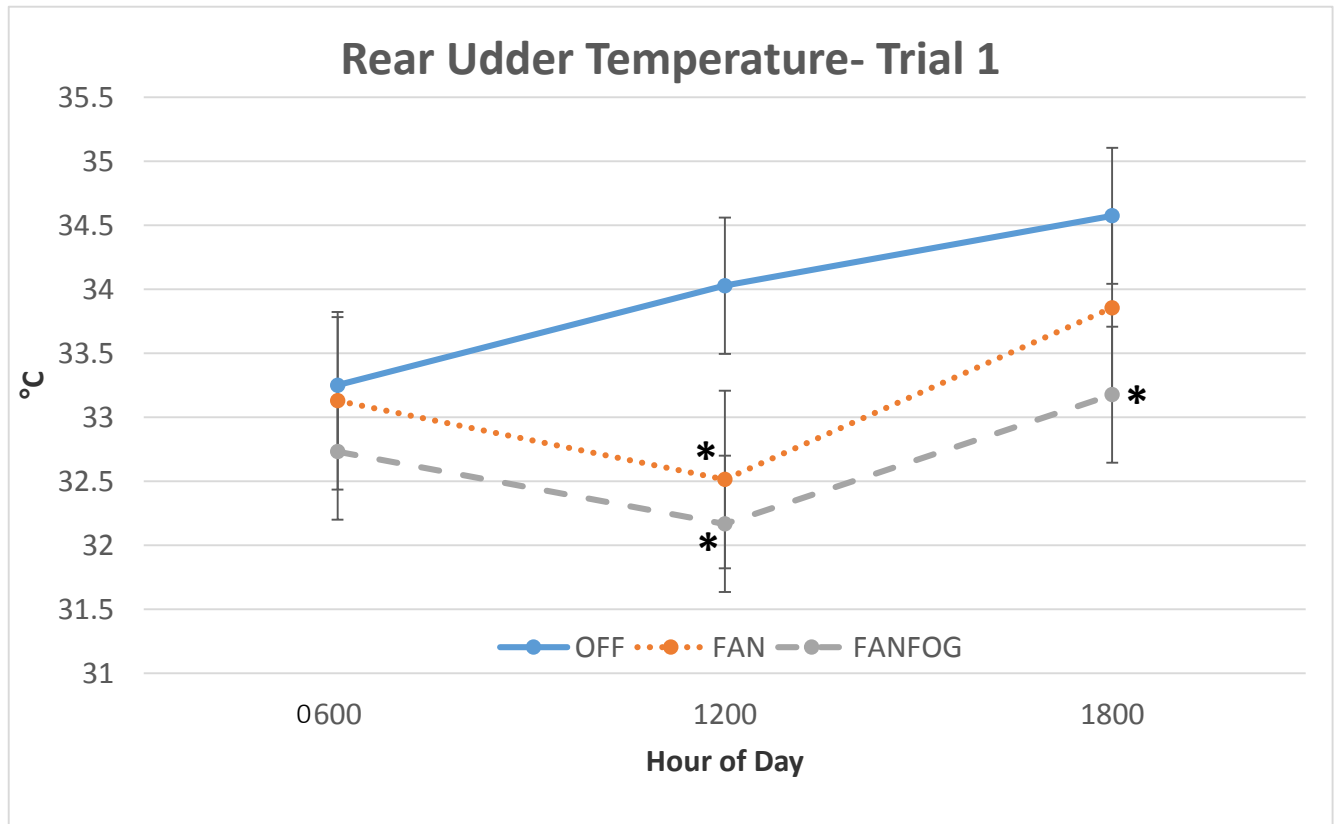


**Figure 2.4** Rear udder temperature during OFF, FAN, and FANFOG for the 2 treatment groups during trial 1.

Environment: OFF = Cows housed without the presence of Cyclone fans or fog; FAN = Cows housed with the presence of Cyclone fans but no fog; FANFOG = Cows housed with the evaporative cooling system in full operation which included Cyclone fans and fog.

Treatment: TIE = Cows housed 50% of the time in the tie-stall barn and 50% of the time in the bedded-pack barn; PACK = Cows housed 50% of the time in the bedded pack barn and 50% of the time in the tie-stall barn moving opposite of TIE.

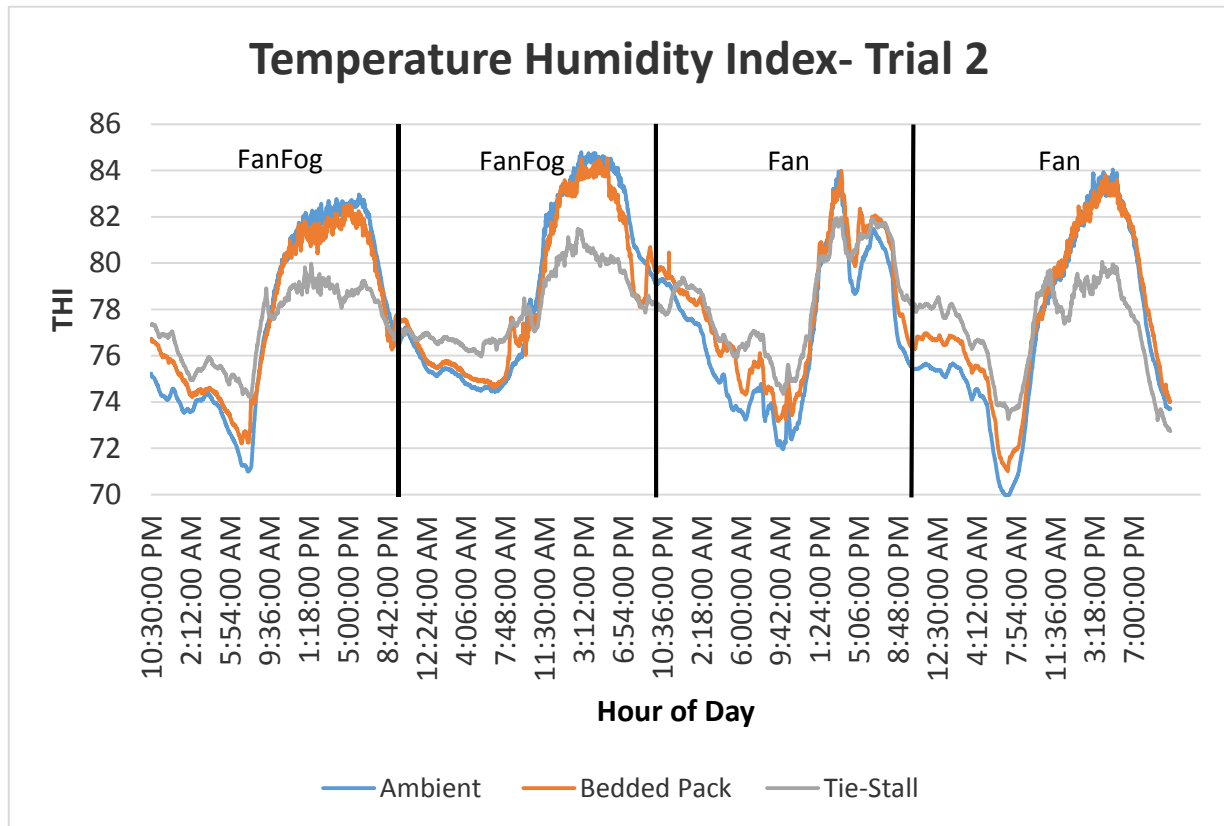
\* $P < 0.05$  vs TIE.



**Figure 2.5** Rear udder temperatures by time period while located in the bedded pack barn during OFF, FAN, or FANFOG for trial 1.

Environment: OFF = Cows housed without the presence of Cyclone fans or fog; FAN = Cows housed with the presence of Cyclone fans but no fog; FANFOG = Cows housed with the evaporative cooling system in full operation which included Cyclone fans and fog.

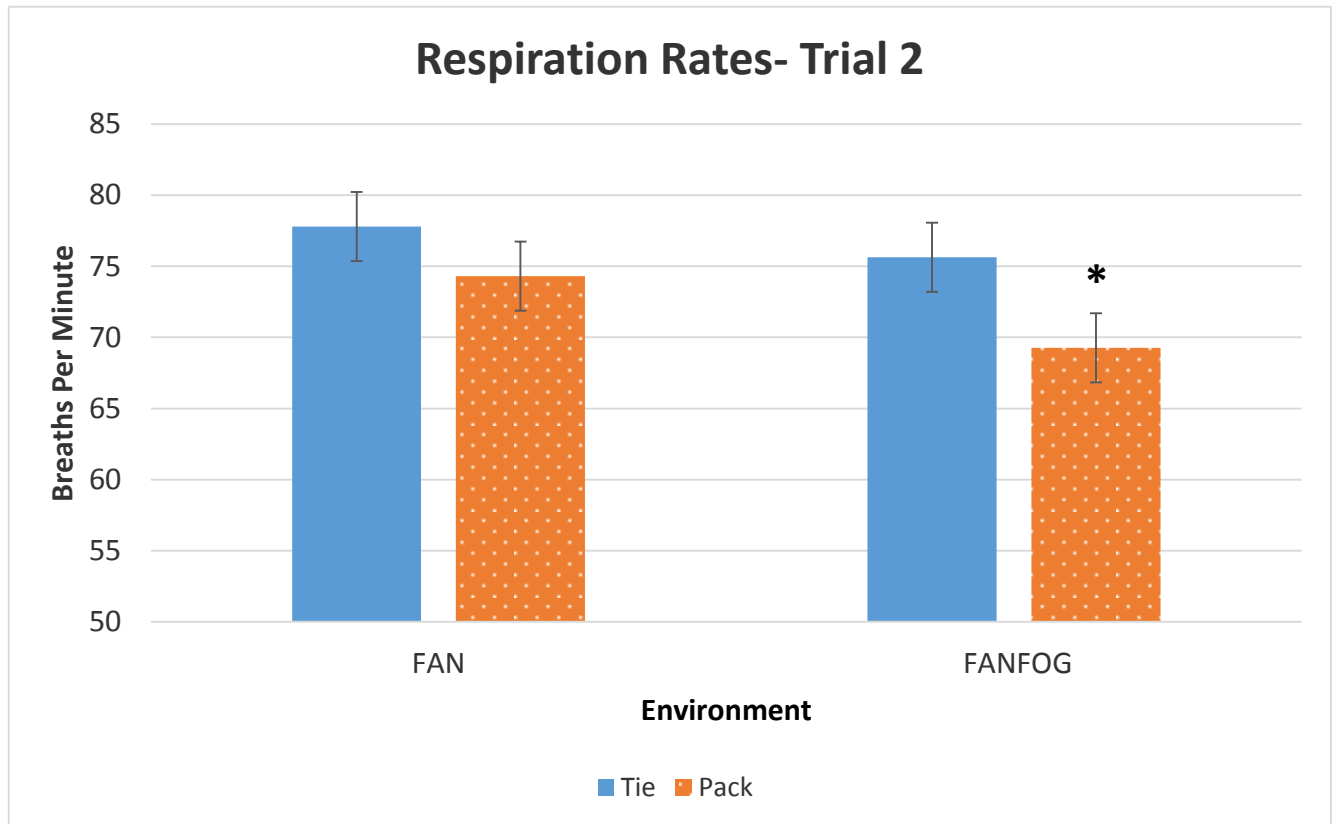
\* $P < 0.05$  vs OFF.



**Figure 2.6** Temperature Humidity Index (THI) for ambient, bedded pack and tie-stall barn conditions for the duration of trial 2. Type of treatment (FAN, or FANFOG) applied for each d is also listed.

Environment: FAN = Cows housed with the presence of Cyclone fans but no fog; FANFOG = Cows housed with the evaporative cooling system in full operation which included Cyclone fans and fog.



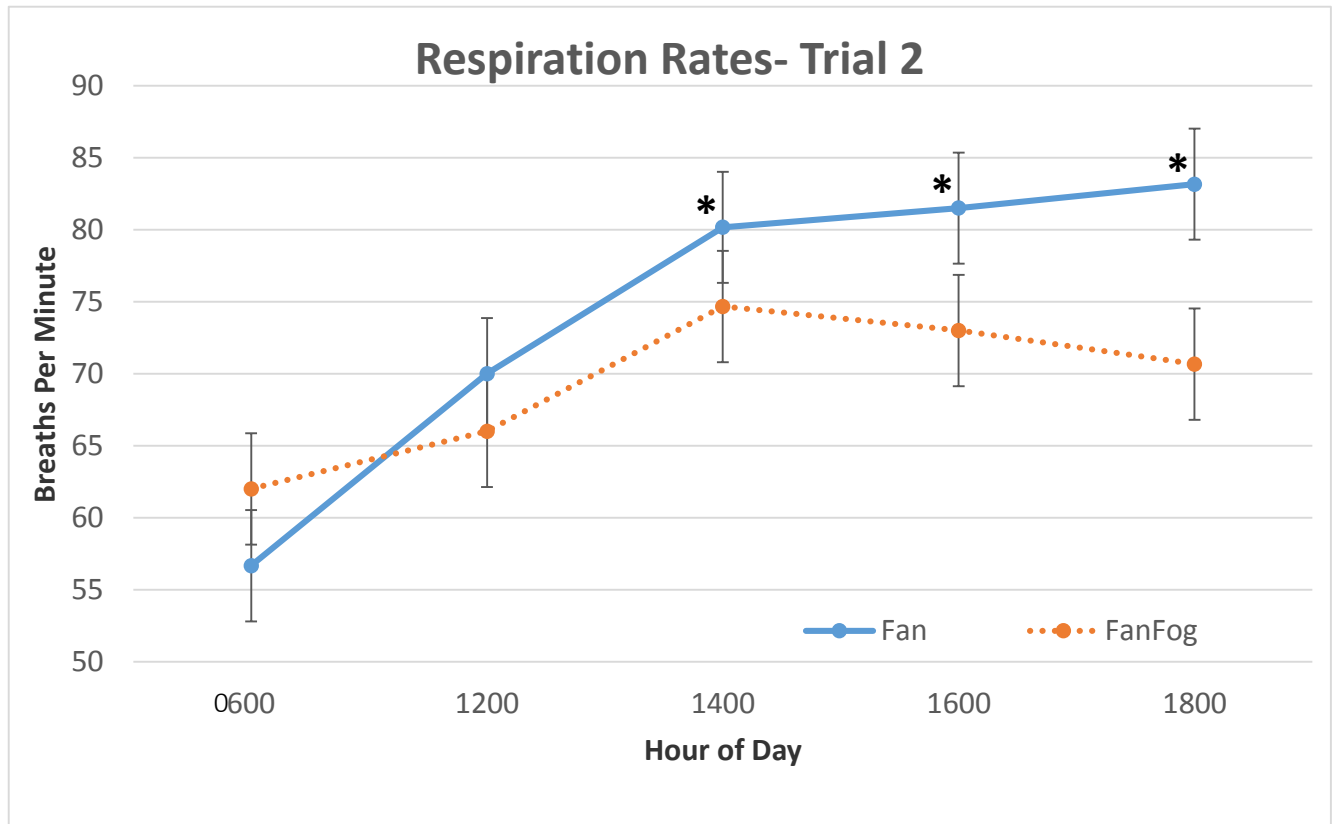


**Figure 2.7** Least squares means for respiration rates, measured in breaths/min (BPM), for the 2 treatment groups during trial 2 while located under FAN or FANFOG.

Environment: FAN = Cows housed with the presence of Cyclone fans but no fog; FANFOG = Cows housed with the evaporative cooling system in full operation which included Cyclone fans and fog.

Treatment: TIE = Cows housed 50% of the time in the tie-stall barn and 50% of the time in the bedded-pack barn; PACK = Cows housed 50% of the time in the bedded pack barn and 50% of the time in the tie-stall barn moving opposite of TIE.

\* $P < 0.05$  vs TIE.



**Figure 2.8** Respiration rates, measured in breaths/min (BPM), by time period while located in the bedded pack barn during FAN or FANFOG for trial 2.

Environment: FAN = Cows housed with the presence of Cyclone fans but no fog; FANFOG = Cows housed with the evaporative cooling system in full operation which included Cyclone fans and fog.

\* $P < 0.05$  vs FAN 0600 h.

**Table 2.1** General parameters for the 2 groups of cows during trials 1 and 2.

Parameters	Treatment <sup>1</sup>	
	TIE	PACK
Lactation	2.17	2.33
Days In Milk	195.0	195.0
Milk, kg	48.6	41.0
Fat, %	3.28	4.10
Protein, %	3.15	3.12
SCC (x 1,000)	100	161

<sup>1</sup>TIE = Cows housed 50% of the time in the tie-stall barn and 50% of the time in the bedded-pack barn; PACK = Cows housed 50% of the time in the bedded pack barn and 50% of the time in the tie-stall barn moving opposite of TIE.

**Table 2.2** Example of cow movement throughout trials 1 and 2.

		Treatment <sup>1</sup>	
	Period <sup>2</sup>	TIE	PACK
Day 1	1	TIE	FANFOG
	2	FANFOG	TIE
	3	TIE	FANFOG
Day 2	1	FANFOG	TIE
	2	TIE	FANFOG
	3	FANFOG	TIE

<sup>1</sup>TIE = Cows housed 50% of the time in the tie-stall barn and 50% of the time in the bedded-pack barn; PACK = Cows housed 50% of the time in the bedded pack barn and 50% of the time in the tie-stall barn moving opposite of TIE.

<sup>2</sup>Each period had a duration of 8 h. Each successive number (period) indicates movement of TIE or PACK to the opposite barn. Thus, it took 2 d (or 6 total periods) to complete 1 treatment.

**Table 2.3** Environmental conditions during the 2 experimental trials.

Parameters	Trial	
	1	2
Temperature, minimum, °C	17.3	21.2
Temperature, maximum, °C	29.2	36.5
Average temperature, °C	22.3	27.7
RH, minimum, %	46.8	39.3
RH, maximum, %	98.8	98.0
RH, average, %	85.5	70.0
Average daily THI	71	78
THI>68, % of time	73.8	100

RH: relative humidity; THI: temperature-humidity index.

$$\text{THI} = (9/5 \times T_{db} + 32) - [0.55 - (0.55 \times \text{RH}/100)] \times [(9/5 \times T_{db} + 32) - 58].$$

**Table 2.4** Effect of evaporative cooling on categorical core body temperature (CBT) for each treatment in min/d during trial 1.

Treatment <sup>1</sup>							
Bedded Pack Barn <sup>2</sup>				Tie-Stall Barn <sup>2</sup>			
CBT <sup>3</sup> , °C	OFF	FAN	FANFOG	OFF	FAN	FANFOG	SE
< 38.6	542.4 <sup>ab</sup>	630.6 <sup>ab</sup>	791.1 <sup>b</sup>	554.5 <sup>ab</sup>	419.7 <sup>a</sup>	402.9 <sup>a</sup>	147.2
≥38.6	505.3 <sup>a</sup>	683.7 <sup>b</sup>	535.9 <sup>ab</sup>	517.7 <sup>ab</sup>	637.4 <sup>ab</sup>	617.8 <sup>ab</sup>	133.2
≥ 39.0	392.3 <sup>a</sup>	125.8 <sup>b</sup>	113.0 <sup>b</sup>	367.8 <sup>a</sup>	382.9 <sup>a</sup>	419.3 <sup>a</sup>	37.6

<sup>1</sup>OFF = Cows housed without the presence of Cyclone fans or fog; FAN = Cows housed with the presence of Cyclone fans but no fog; FANFOG = Cows housed with the evaporative cooling system in full operation which included Cyclone fans and fog.

<sup>2</sup>Bedded Pack Barn = barn where cows were housed with the evaporative cooling system (Cyclone Fans); Tie-Stall Barn = barn where cows were housed with cooling cells but no Cyclone Fans.

<sup>3</sup>CBT was broken into 3 categories: min/d with CBT < 38.6°C; min/d with CBT ≥ 38.6°C but < 39.0°C; min/d with CBT ≥ 39.0°C.

<sup>a,b</sup>Means within row with different superscripts differ ( $P \leq 0.05$ ).

**Table 2.5** Effect of evaporative cooling on categorical core body temperature (CBT) for each treatment in min/d during trial 2.

CBT <sup>3</sup> , °C	Treatment <sup>1</sup>				SE
	Bedded Pack Barn <sup>2</sup>		Tie-Stall Barn <sup>2</sup>		
	FAN	FANFOG	FAN	FANFOG	
< 38.6	243.0	302.9	48.2	66.7	49.5
≥ 38.6	318.5 <sup>a</sup>	585.2 <sup>b</sup>	171.3 <sup>a</sup>	312.7 <sup>a</sup>	27.1
≥ 39.0	878.5 <sup>a</sup>	551.9 <sup>b</sup>	1220.5 <sup>c</sup>	1060.7 <sup>ac</sup>	57.5

<sup>1</sup>FAN = Cows housed with the presence of Cyclone fans but no fog; FANFOG = Cows housed with the evaporative cooling system in full operation which included Cyclone fans and fog.

<sup>2</sup>Bedded Pack Barn = barn where cows were housed with the evaporative cooling system (Cyclone Fans); Tie-Stall Barn = barn where cows were housed with cooling cells but no Cyclone Fans.

<sup>3</sup>CBT was broken into 3 categories: min/d with CBT < 38.6°C; min/d with CBT ≥ 38.6°C but < 39.0°C; min/d with CBT ≥ 39.0°C.

<sup>a,b,c</sup>Means within row with different superscripts differ ( $P \leq 0.05$ ).

**Table 2.6** Effect of evaporative cooling on total lying and standing time during Trial 1.

Item, min/d	Treatment <sup>1</sup>						SE
	Bedded Pack Barn <sup>2</sup>			Tie-Stall Barn <sup>2</sup>			
	OFF	FAN	FANFOG	OFF	FAN	FANFOG	
Lying Time	518.1 <sup>a</sup>	682.2 <sup>ab</sup>	710.8 <sup>b</sup>	750.2 <sup>b</sup>	715.3 <sup>b</sup>	738.1 <sup>b</sup>	34.9
Standing Time	921.9 <sup>a</sup>	757.8 <sup>ab</sup>	729.3 <sup>b</sup>	689.8 <sup>b</sup>	724.7 <sup>b</sup>	701.9 <sup>b</sup>	34.9

<sup>1</sup>OFF = Cows housed without the presence of Cyclone fans or fog; FAN = Cows housed with the presence of Cyclone fans but no fog; FANFOG = Cows housed with the evaporative cooling system in full operation which included Cyclone fans and fog.

<sup>2</sup>Bedded Pack Barn = barn where cows were housed with the evaporative cooling system (Cyclone Fans); Tie-Stall Barn = barn where cows were housed with cooling cells but no Cyclone Fans.

<sup>a,b</sup>Means within row with different superscripts differ ( $P \leq 0.05$ ).

**Table 2.7** Effect of evaporative cooling on total lying and standing time during Trial 2.

Item, min/d	Treatment <sup>1</sup>				SE
	Bedded Pack Barn <sup>2</sup>		Tie-Stall Barn <sup>2</sup>		
	FAN	FANFOG	FAN	FANFOG	
Lying Time	475.1	504.4	632.8	616.1	60.7
Standing Time	964.9	935.6	807.3	823.9	60.7

<sup>1</sup>FAN = Cows housed with the presence of Cyclone fans but no fog; FANFOG = Cows housed with the evaporative cooling system in full operation which included Cyclone fans and fog.

<sup>2</sup>Bedded Pack Barn = barn where cows were housed with the evaporative cooling system (Cyclone Fans); Tie-Stall Barn = barn where cows were housed with cooling cells but no Cyclone Fans.

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# **Chapter 3 - Use of Evaporative Cooling Systems and its Effects on Core Body Temperature and Lying Times in Nonlactating Dairy Cows**

## **Abstract**

A study was performed to assess the effect of an evaporative cooling system (ECS) on core body temperature (CBT), and lying times in nonlactating dairy cows. The study was performed in a straw pack barn equipped with an ECS (Cyclone fans). 10 nonlactating Holstein dairy cows were selected at random for this study which consisted of 2 treatments: FAN (Cyclone fans only, no fog), and FANFOG (Cyclone fans and fog on). All cows were housed under the FAN treatment on d 1 and switched to FANFOG at the start of d 2. Each cow was fitted with a vaginal temperature logger (HOBO U12, Onset Computer Corporation, Pocasset, MA), a neck collar that contained a sensor (HOBO Pro V2, Onset Computer Corporation, Pocasset, MA) to track temperature and relative humidity of the cows microenvironment, and an electronic data logger (HOBO Pendant G Acceleration Data Logger, Onset Computer Corporation, Pocasset, MA) to track lying times. Ambient temperature and relative humidity (RH) were also recorded and all devices recorded at 1 min intervals.

Ambient THI were similar when averaged over the entire d but differences were found within d by h. The average maximum ambient temperature of the 2 d was 35.4°C during FAN and 34.3°C during FANFOG. Using neck collar sensors to track microenvironment changes, the FANFOG treatment showed reduced collar THI compared to FAN, although no differences were found during afternoon h.

FANFOG cows had reduced CBT during the afternoon h coinciding with the hottest time of d. Categorical temperature data were assessed using the following categories for CBT: < 38.0°C, ≥ 38.0°C but < 39.0°C, and ≥ 39.0°C. FANFOG cows spent 283.6 fewer min/d at a CBT ≥ 39.0°C ( $P = 0.01$ ) and 126.8 min/d more at a CBT < 38.6°C ( $P = 0.13$ ) compared to FAN. Individual cow lying times were also assessed for each cow. FANFOG treatment had increased lying time/d ( $P < 0.0001$ ) with an overall mean of  $864.2 \pm 46.0$  h vs  $764.7 \pm 46.0$  for FAN.

Results from this study confirm that the ECS used is effective in decreasing CBT and increasing lying times in nonlactating dairy cows.

**Key words:** heat stress, evaporative cooling, core body temperature, lying behavior

## Introduction

Heat stress greatly affects dairy cattle behavior and physiology (Collier et al., 2006) every year throughout the U.S. Not only does heat stress reduce milk production but it greatly decreases efficiencies for growth and reproduction and leads to animal welfare issues such as lameness. It has been estimated that heat stress costs the U.S. dairy industry ~\$900 million annually (St-Pierre et al., 2003). More recently, Scharf et al. (2014), estimated heat stress to have an economic impact of \$89.01/cow per year. Even though much progress has been made over the years limiting the effects of heat stress on dairy cattle, we continue to see many negative effects of heat stress annually as milk production and metabolic heat production continue to increase in today's high producing dairy cows.

Previous research has shown the importance of cooling dairy cows during the dry period (do Amaral et al., 2011; Tao et al., 2012b; Thompson et al., 2012). Heat stressed dry cows have a decreased immune system which leads to increased metabolic issues postpartum (do Amaral et al., 2011; Thompson et al., 2012). In addition, when dairy cows are heat stressed during the dry period, dry matter intake declines leading to greater metabolic disease postpartum as well as decreased production in the subsequent lactation due to compromised mammary gland development (Tao et al., 2011; Monteiro et al., 2014). In addition to negative effects on cows, heat stress during late gestation is associated with decreased birth weights of calves and decreased serum IgG levels indicating reduced absorption of colostral IgG leading to greater disease incidence early in life (Collier et al., 1982; Tao et al. 2012a).

Evaporative cooling systems equipped with a fogging mechanism have been used to decrease the air temperature around the cow and increase the heat exchange between the cow and environment (Berman, 2006). The fog cools the air as it moves through the facility aided by the movement of air provided by strategically placed fans throughout the facility. Our objective was

to evaluate the effect of using high velocity fans equipped with a fogging system on vaginal temperature and lying times of nonlactating Holstein dairy cows.

## **Materials and Methods**

### ***Animals and Facilities***

Ten nonlactating Holstein dairy cows averaging 1.6 lactations, 54 days dry, and 264 days in gestation were selected at random for this trial. The trial was conducted on a commercial dairy in central Kansas that consisted of a straw pack barn fitted with an evaporative cooling system (ECS) that consisted of 2 Cyclone fans (CYC723230460, 1.83 m Cyclone with deflectors, 230/460V, 3 HP) provided by VES Environmental Solutions (Chippewa Falls, WI). The Cyclone fans were placed over the straw pack area and were fitted with a fogging system to aid in cooling the cows that could be turned off if needed. The fog system ran at ~1,000 PSI resulting in a water droplet size of 10-17 microns with a flow rate of ~0.036 gal/min/nozzle with 15 nozzles/fan. The fog was sprayed into the air in front of the fan via 3 spray bars. The trial was conducted from September 3 to September 4, 2014. A total mixed ration was fed once daily during the trial to meet or exceed the predicted nutrient requirements (NRC, 2001) for energy, protein, vitamins, and minerals. The Institutional Animal Care and Use Committee at Kansas State University approved all experimental procedures.

### ***Experimental Design and Treatments***

All 10 cows were exposed to the same treatments. Day 1 of the trial was conducted with the Cyclone fans only and no fogging system (**FAN**). Day 2 consisted of both the Cyclone fans and fogging system (**FANFOG**).

Ambient temperature and relative humidity were measured at 1 min intervals by 2 weather stations located on the farm. The weather station consisted of a sensor (HOBO Pro V2, Onset Computer Corporation, Pocasset, MA) and a solar radiation and moisture shield (M-RSA; Onset Computer Corporation, Pocasset, MA). Inside the straw pack barn, a weather station (HOBO Pro V2, Onset Computer Corporation, Pocasset, MA) was placed in a central location of the barn to track barn temperature and relative humidity, also at 1 min intervals.

Each cow in the study was fitted with a neck collar that contained a sensor (HOBO Pro V2, Onset Computer Corporation, Pocasset, MA) to track temperature and relative humidity of the environment as the cow moved throughout the facility. Each cow also received an intravaginal stainless steel temperature logger (HOBO U12, Onset Computer Corporation, Pocasset, MA) attached to a blank controlled internal drug-releasing device (CIDR; Pfizer Animal Health, New York, NY) that recorded vaginal temperature at 1 min intervals beginning at midnight on d 1 of the study. In addition, each cow was fitted with an electronic data logger (HOBO Pendant G Acceleration Data Logger, Onset Computer Corporation, Pocasset, MA) that was attached to the medial side of the right, hind leg by using vet wrap. The acceleration data logger was placed in a position such that the x-axis was parallel to the ground, the y-axis was perpendicular to the ground pointing upward, and the z-axis was parallel to the ground pointing away from the sagittal plane. The loggers recorded the g-force on the x, y, and z-axes at 1 min intervals for 2 d. All devices were pre-programmed to begin recording at midnight on d 1 of the study. Each of the data loggers were removed from each cow at the end of the study period and data were downloaded using Onset HOBOWare software (Onset Computer Corporation, Pocasset, MA), which converted the g-force readings into degrees of tilt. These data were exported into Microsoft Excel (Microsoft Corporation, Redmond, WA), and the degree of vertical tilt (y-axis) was used to determine the lying position of the animal, such that readings  $< 60^\circ$  indicated the cow standing, whereas readings  $\geq 60^\circ$  indicated the cow lying down (Ito et al., 2009). Standing and lying bouts of  $< 2$  min were ignored because these readings were likely associated with leg movements at the time of recording (Endres and Barberg, 2007). Nine of the 10 data loggers were programmed and managed by a single computer, allowing for synchronization of time. One cow was removed from the study due to loss of the data logger device.

### ***Statistical Analysis***

Data for ambient and barn conditions, collar data, vaginal temperature and lying times were averaged by h prior to data analysis. A randomized complete block design with hour as the repeated measure and cow within treatment as the subject was used in the Proc MIXED procedure of SAS (version 9.4, SAS Institute Inc., Cary, NC) was used. Cow was used as a

random blocking factor, while treatment (FAN or FANFOG) was the fixed effect. Treatments were compared using least squares means within each hour of day and also averaged across hours. The heterogeneous first-order auto regressive covariance structure was used for repeated measures on each cow, while Satterthwaite's approximation was used to calculate the denominator degrees of freedom. Significance was declared with a *P*-value of  $\leq 0.05$ , and trends were declared with a *P*-value between  $> 0.05$  and  $\leq 0.10$ .

Mean hourly temperature humidity index (**THI**) data was calculated using the formula  $THI = (9/5 \times T_{db} + 32) - [0.55 - (0.55 \times RH/100)] \times [(9/5 \times T_{db} + 32) - 58]$ , where  $T_{db}$  is dry-bulb temperature ( $^{\circ}C$ ; Zimbelman et al., 2009). Vaginal temperatures were used to determine mean 24-h CBT and mean hourly CBT. In addition, CBT data were used to determine the duration of time cows maintained a CBT above or below various temperatures each d. Lying behavior data were summarized by analyzing the angles recorded by the leg data loggers and then total lying time was calculated for each cow.

## Results and Discussion

Ambient temperature, relative humidity, and THI data for both treatments can be found in Table 3.1. FAN had greater ambient temperature but lesser relative humidity (**RH**) levels in comparison to FANFOG resulting in similar, but statistically different average daily THI for each treatment. A rain event at the end of d 1 (FAN) occurred thus affecting temperature and RH levels at the start of d 2 (FANFOG) as shown by the drastic drop in THI levels at 0000 h in Fig. 3.2. It is interesting to note that even with similar barn and collar THI levels seen on d 2 during FANFOG, FANFOG was able to maintain decreased CBT levels during the hottest time of d. Treatment by h interactions were found for ambient THI with FAN having greater THI from 0000 to 0800 h while FANFOG had greater THI from 0800 to 2300 h (Fig. 3.1).

Cows with evaporative cooling (FANFOG) had numerically decreased mean 24-h core body temperature (**CBT**) vs cows without evaporative cooling (fan only; FAN) ( $39.3 \pm 0.13$  and  $39.5 \pm 0.13^{\circ}C$ , respectively), although these results were not significant ( $P = 0.12$ ). A treatment by h interaction ( $P < 0.0001$ ), however, was observed. The greatest time effect occurred at 1200 h; treatment means at this time were  $39.7 \pm 0.17^{\circ}C$  and  $39.2 \pm 0.17^{\circ}C$  for FAN and FANFOG treatments, respectively (Fig. 3.3). Although we did not find a difference in CBT, the numerical

decrease in CBT during FANFOG (specifically in the afternoon h even though FANFOG had increased THI levels throughout the afternoon) in this study, was a result of evaporative cooling from the combination of Cyclone fans and fog. Cows in this study were under a great deal of heat stress. The ECS was effective in cooling the cow environment as evidenced by decreasing the difference in THI between ambient conditions and THI levels seen at the collar during FAN and FANFOG. This resulted in increased efficiency of heat loss due to greater evaporative cooling allowing the cow to maintain decreased CBT. The lack of a significant treatment effect could have possibly been avoided by adding more cows to the trial or lengthening the duration of the trial.

When looking at categorical CBT (Table 3.2), FAN treatment resulted in elevated CBT  $\geq 39.0^{\circ}\text{C}$  for 4.7 more h/d ( $P = 0.01$ ) compared to cows housed under FANFOG. We found a numerical difference for time/d spent below  $38.6^{\circ}\text{C}$  where cows housed under FANFOG spent 2.1 more h/d at CBT  $< 38.6^{\circ}\text{C}$  compared to cows on the FAN treatment ( $P = 0.13$ ).

The effects of cooling dairy cows during the dry period has been studied extensively in recent years (do Amaral et al., 2011; Tao and Dahl, 2013; Monteiro et al., 2014). In comparison to lactating cows, dry cows produce less metabolic heat (West, 2003) and have a greater upper critical temperature (Hahn, 1997). Dry cows still become heat stressed, however, which can greatly affect performance during late gestation and early postpartum. Cows exposed to heat stress during late gestation showed decreased milk production in the following lactation (Wolfenson et al. 1988; do Amaral et al., 2009; Tao et al. 2011). Tao et al. (2011) cited these losses as a result of reduced mammary gland development due to impaired mammary epithelial cell proliferation rate. Also, cows cooled during the prepartum period mobilize greater amounts of adipose tissue leading to increased blood NEFA and BHBA and decreased glucose levels compared to heat stressed cows (do Amaral et al., 2009; Tao et al., 2012b). Due to greater adipose tissue mobilization, greater nutrients are available to support milk production postpartum. In addition to postpartum milk loss, heat stressed dry cows are more likely to have impaired immune function resulting in increased incidence of metabolic disorders and altered fetal growth and calf development (do Amaral et al., 2011; Thompson and Dahl, 2012; Monteiro et al., 2014). It was found that neutrophil function was reduced in heat stressed cows compared to cooled cows, thus less able to fight off an invading infection during transition. In the same study, cooled cows responded with superior production of IgG compared to their heat stressed



counterparts indicating impaired humoral immunity during late gestation (do Amaral et al., 2011). Reproduction can also be affected from heat stress during the dry period due to greater metabolic disorders leading to uterine infections which could lead to greater d to first service. Thompson and Dahl (2012) compared cows that were dry during hot months (June, July, and August) to cows dry during cool months (December, January, February) and found greater days in milk (DIM) to pregnancy as well as greater DIM to first breeding.

By applying a sensor to the neck collar of each cow in this study, we were able to track temperature and RH levels of the microenvironment the cow was exposed to as she moved throughout the facility. We thought this would be a better indicator than relying on sensors placed within the barn as the neck collar sensor would give us a better indicator of the micro-environmental conditions the cow is actually exposed to within the barn throughout the d. Due to the close proximity of the sensor to the cow's body, collar sensor readings were greater than barn and outside ambient sensors due to heat given off from the cow's body surface. Collar THI readings averaged 2.1 THI greater vs actual barn THI. While this prevented us from comparing collar temperature data to barn and ambient temperature data directly, we were able to compare between cow collar temperature data effectively although we do recognize there could be a slight confounding factor of differences between cows for total body heat production. Collar THI data by h of d can be found in Fig. 3.4. We found a treatment effect ( $P = 0.0005$ ) for FAN vs. FANFOG with the FANFOG treatment showing reduced collar THI compared to FAN;  $79.6 \pm 0.18^{\circ}\text{C}$  and  $80.1 \pm 0.18^{\circ}\text{C}$ , respectively. Much of the effect, however, was found in the early morning h while no differences in collar THI were found during the hottest part of the d. We attributed the early morning differences in collar THI on d 2 to the rain event that occurred near the end of d 1. This resulted in a treatment by h interaction with cooler CBT seen during the FANFOG treatment, particularly during the afternoon h.

The ECS incorporated a very fine mist or fog into the air which cools the environment as it evaporates. This leads to an increased temperature gradient between the cow and the surrounding environment allowing the cow to cool herself more effectively. If using an ECS such as in this study, it is important to realize that as air temperature is reduced due to water evaporation, the potential to evaporate moisture from the skin of cattle is also reduced due to greater RH levels. The net effect of evaporative cooling of air must be greater than the loss of cooling from moisture evaporation from the skin of cattle (Collier et al., 2006). Otherwise, heat

stress will increase. The ECS and fogging system produced water droplets of just 10-17 microns in diameter by applying 1,000 PSI. By placing 3 spray bars in front of the high velocity fans, evaporation of water droplets was not a problem until RH levels became too great. Future research should aim to design a system that allows moisture (fog) levels to be adjusted based on RH levels of the environment which may not be the same for all fans throughout the facility.

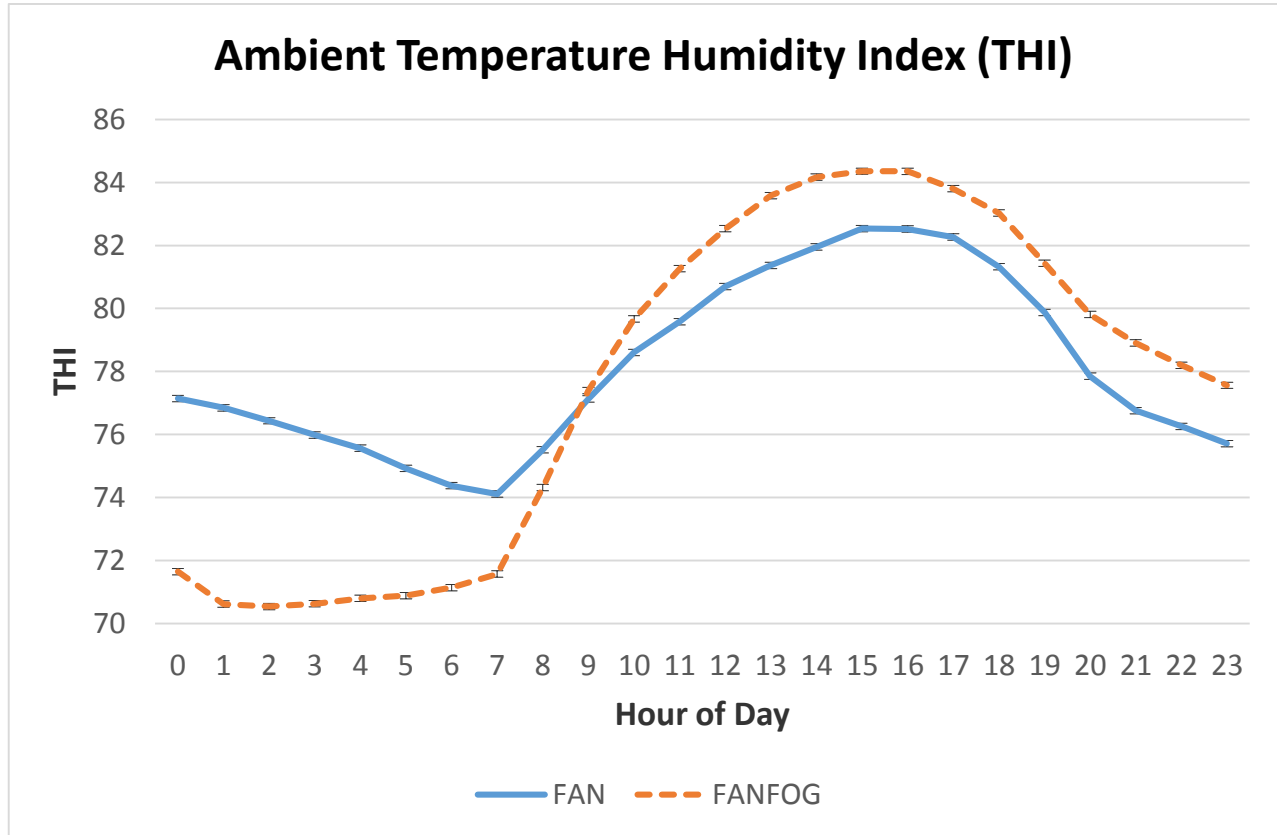
Total lying and standing times can be found in Table 3.3. Greater lying times ( $P < 0.0001$ ) were found when cows were housed under FANFOG compared to FAN. During FANFOG, cows were lying down for 1.7 h/d more in comparison to FAN (14.4 vs 12.7 h/d, respectively). Increased lying time is an indicator that cows were more comfortable during FANFOG as cows tend to increase standing time when heat stressed (Cook et al., 2007) in an attempt to increase body surface area resulting in increased sensible water loss, radiating surface, and convective cooling. Both groups of cows, however, had adequate lying times as healthy dairy cattle maintain 12 to 13 h/d of lying time (Cook et al., 2004).

It would be a great benefit in the future to be able to run another similar trial with more cows and more d in order to magnify any treatment effects. Also, the rain event at the end of d 1 likely skewed the results somewhat due to its effect on ambient temperature and RH. Although we had no control over environmental conditions, running another trial during dry conditions would be advised.

## **Conclusions**

The ECS used in this study was effective in decreasing CBT as shown by the reduction in hours spent at greater stress levels ( $> 39.0^{\circ}\text{C}$ ). In addition, cows spent increased h/d lying down during FANFOG in comparison to FAN. The ECS was effective in reducing barn THI as demonstrated by similar microenvironmental conditions at the collar during FANFOG even though ambient THI was greater during FANFOG. This is a result of the fog during FANFOG cooling the air within the barn which allowed the cows to feel cooler as evidenced by decreased CBT (reduced time spent above  $39.0^{\circ}\text{C}$ ) and increased lying times. Because of the decrease in CBT and increase in total daily lying times in this study, we conclude that the ECS used was effective and increased cow comfort during heat stress conditions.

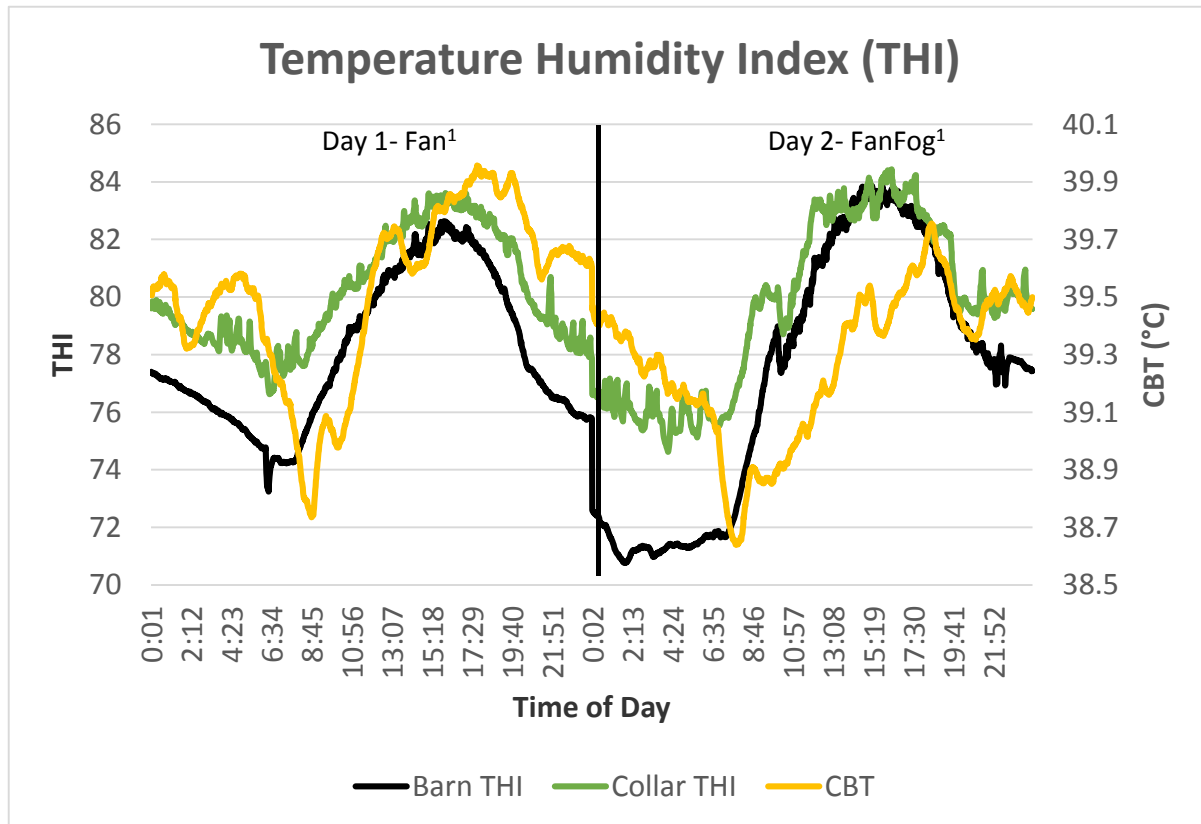
## Figures and Tables



**Figure 3.1** Average ambient temperature humidity index (THI) levels for FAN and FANFOG by h throughout the duration of the trial.

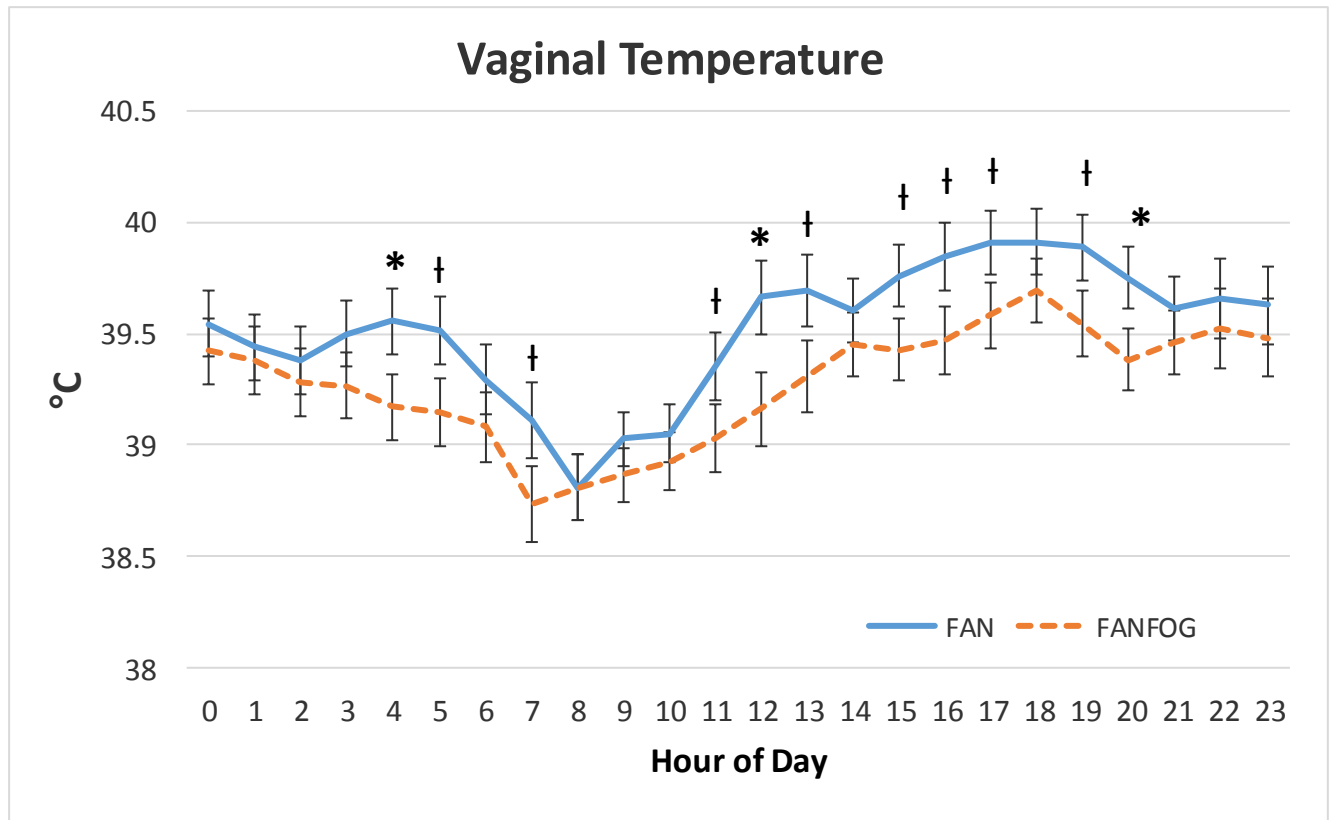
Treatment: FAN = Cows housed with the presence of Cyclone fans but no fog; FANFOG = Cows housed with the evaporative cooling system in full operation which included Cyclone fans and fog.

Treatment Effect:  $P < 0.0001$ .



**Figure 3.2** Average barn and collar THI data along with core body temperature (CBT) during each d of the study.

<sup>1</sup>Treatment: FAN = Cows housed with the presence of Cyclone fans but no fog; FANFOG = Cows housed with the evaporative cooling system in full operation which included Cyclone fans and fog.



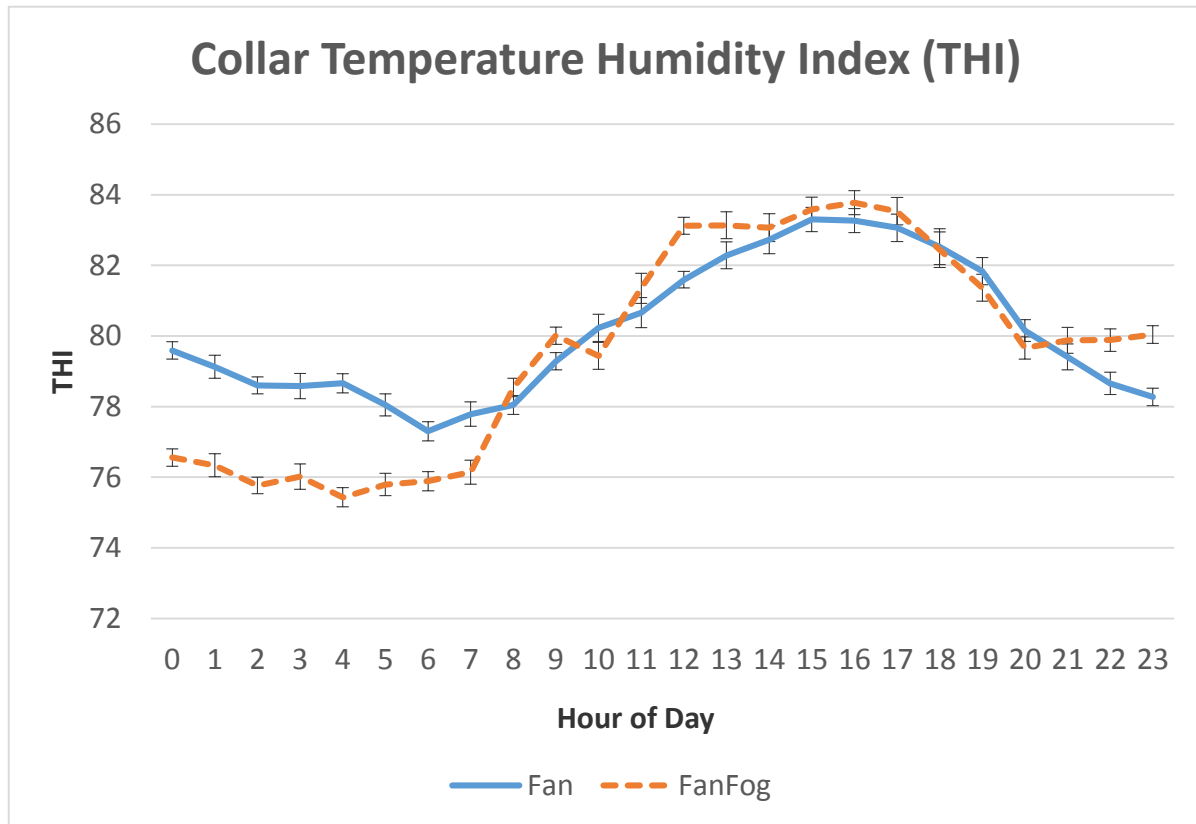
**Figure 3.3** Average vaginal temperatures (CBT) over a 24 h period while cows were housed under FAN or FANFOG.

Treatment: FAN = Cows housed with the presence of Cyclone fans but no fog; FANFOG = Cows housed with the evaporative cooling system in full operation which included Cyclone fans and fog.

Treatment effect:  $P = 0.12$ .

\* $P \leq 0.05$ .

† $P \leq 0.10$ .



**Figure 3.4** Average collar temperature humidity index (THI) over a 24 h period while cows were housed under FAN or FANFOG.

Treatment: FAN = Cows housed with the presence of Cyclone fans but no fog; FANFOG = Cows housed with the evaporative cooling system in full operation which included Cyclone fans and fog.

Treatment effect:  $P = 0.0005$ .

**Table 3.1** Average ambient conditions for each treatment throughout the duration of the trial.

Parameters	Treatment <sup>1</sup>	
	FAN	FANFOG
Temperature, minimum, °C	24.9	21.7
Temperature, maximum, °C	35.4	34.3
Average temperature, °C	29.6	27.8
RH, minimum, %	35.8	52.2
RH, maximum, %	72.9	91.8
RH, average, %	55.1	71.5
THI, minimum	74.1	70.5
THI, maximum	82.5	84.4
Average daily THI	78.1	77.6

RH: relative humidity; THI: temperature-humidity index.

$$\text{THI} = (9/5 \times T_{db} + 32) - [0.55 - (0.55 \times \text{RH}/100)] \times [(9/5 \times T_{db} + 32) - 58].$$

<sup>1</sup>FAN = Cows housed with the presence of Cyclone fans but no fog; FANFOG = Cows housed with the evaporative cooling system in full operation which included Cyclone fans and fog.

**Table 3.2** Effect of evaporative cooling on categorical core body temperature (CBT) for each treatment in min/d.

CBT <sup>2</sup> , °C	Treatment <sup>1</sup>		SE	<i>P</i> -value
	FAN	FANFOG		
< 38.6	46.9	173.7	62.7	0.13
≥ 38.6	236.2	393.0	95.2	0.04
≥ 39.0	1156.9	873.3	136.1	0.01

<sup>1</sup>FAN = Cows housed with the presence of Cyclone fans but no fog; FANFOG = Cows housed with the evaporative cooling system in full operation which included Cyclone fans and fog.

<sup>2</sup>CBT was broken into 3 categories: min/d with CBT < 38.6°C; min/d with CBT ≥ 38.6°C but < 39.0°C; min/d with CBT ≥ 39.0°C.

**Table 3.3** Effect of evaporative cooling on total lying and standing time.

Item, min/d	Treatment <sup>1</sup>		SE	<i>P</i> -value
	FAN	FANFOG		
Lying Time	764.7	864.2	46.0	< 0.0001
Standing Time	675.3	575.8	46.0	< 0.0001

<sup>1</sup>FAN = Cows housed with the presence of Cyclone fans but no fog; FANFOG = Cows housed with the evaporative cooling system in full operation which included Cyclone fans and fog.

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## **Chapter 4 - Overall Summary**

Overall, the ECS (Cyclone fans and fog) used in each study was effective in reducing heat stress in lactating and non-lactating dairy cattle. By looking at total daily min/d spent above a critical temperature (39.0°C), we were able to show that cows were able to maintain decreased CBT as evidenced by decreased time spent above 39.0°C CBT and greater time/d below 38.6°C. Total daily lying time also increased for cows housed under the ECS. This is an indicator that cows were more comfortable and less heat stressed since it has been shown in previous research that cows tend to increase standing time when heat stressed. Lying time is very important in that there is a positive relationship between lying times and milk production. Respiration rates were also shown to decrease giving more evidence that the ECS was effective.

Under the circumstances of this study, the cyclone fan and fog system was more effective at cooling cows when compared to another type of ECS (cooling cells in the tie-stall barn). This type of ECS (Cyclone fans) also uses less water when compared to cooling cells or feed bunk sprinklers which is becoming more important with increased talk about daily water use on dairies today. For this system to work effectively, sensors should be placed throughout the facility to track temperature and RH levels which in turn, determine fan velocity and fogging level or frequency versus the producer having to manually turn the system on and off. Often times, the producer becomes busy and will forget about the system resulting in either an excessively wet environment or excessive time without the fog being turned on. This will help in preventing extreme RH levels within the barn as this can worsen the heat stress experienced by the cow. Also, one must check that the bedding surface does not become wet. This will not be an issue unless RH levels become too great.

Future research should include studies conducted in an effort to determine proper fogging frequency and levels based on temperature and RH levels within the barn. It would be beneficial to grid each barn prior to installation and within each grid, place a temperature and RH sensor that communicates with a central control box which determines the fan velocity as well as the fogging level and frequency for each fan within the barn.. It would also be beneficial to have the option of applying fog from just 1 or 2 spray bars vs an all-on or all-off method. It is likely that

not all fans will always be operating at the same velocity and fogging level or frequency. As air moves through the barn, it will increase in RH; therefore Cyclone fans located farther from the inlet or closer to the exhaust fans will likely need to have reduced fogging frequency or levels either by spraying from just 1 or 2 spray bars or increasing time between fogging events for that fan.